



Working Paper 284

Monetary Policy and Firm-Level Productivity:
Financial Frictions, Theory, and Causal Evidence

Karin Klieber, Michael Sigmund, Maria T. Valderrama

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We study how monetary policy affects firm-level total factor productivity in the presence of financial frictions using a panel of Austrian non-financial firms. A dynamic firm model and causal empirical framework show that tighter monetary policy reduces productivity-enhancing investment and firm-level TFP. The effects are stronger for highly leveraged firms and are more pronounced for persistent changes in financing conditions than for transitory high frequency policy surprises.

Authors

Karin Klieber,
Oesterreichische Nationalbank
Monetary Policy
karin.klieber@oenb.at

Michael Sigmund,
Oesterreichische Nationalbank
Monetary Policy
michael.sigmund@oenb.at

María T. Valderrama
Oesterreichische Nationalbank
Monetary Policy
maria.valderrama@oenb.at



Monetary tightening lowers firm productivity

Monetary tightening lowers total factor productivity, consistent with higher financing costs reducing firms' ability to undertake productivity-enhancing investment.



Persistent financing conditions matter most

Monetary tightening lowers total factor productivity, consistent with higher financing costs reducing firms' ability to undertake productivity-enhancing investment.



Financial frictions amplify transmission

Highly leveraged firms experience stronger productivity losses following monetary tightening. At the aggregate level, improvements in average firm productivity are partly offset by declining allocative efficiency.

Opinions expressed by the authors of studies do not necessarily reflect the official viewpoint of the Oesterreichische Nationalbank or the Eurosystem.

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 Papoutsis 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](#).

Monetary Policy and Firm-Level Productivity: Financial Frictions, Theory, and Causal Evidence

Karin Klieber¹, Michael Sigmund¹, Maria T. Valderrama¹

Abstract

We study how monetary policy affects firm-level total factor productivity in the presence of financial frictions using a panel of Austrian non-financial firms. We develop a dynamic optimization model in which monetary policy influences firms' investment in physical capital and productivity-enhancing technologies through borrowing constraints and financing conditions. The model predicts that the productivity effects of monetary policy depend crucially on the tightness of financial constraints. Guided by this framework, we combine directed acyclic graphs with panel regression techniques to identify the causal effects of monetary policy on firm-level productivity. Our empirical results show that contractionary monetary policy significantly reduces total factor productivity. Moreover, firms with higher leverage exhibit significantly stronger productivity responses to monetary tightening, consistent with borrowing constraints amplifying the transmission of monetary policy. In particular, changes in policy rates and persistent deviations from rule-based policy rates have substantially larger effects on productivity than high-frequency monetary policy shocks. The findings suggest that firms respond primarily to persistent changes in financing conditions rather than to transitory monetary surprises. Overall, the results highlight the central role of financial constraints in the transmission of monetary policy to firm-level productivity and long-run economic performance.

Keywords: total factor productivity; monetary policy shocks; financial frictions

Email addresses: karin.klieber@oenb.at (Karin Klieber), michael.sigmund@oenb.at (Michael Sigmund), maria.valderrama@oenb.at (Maria T. Valderrama)

¹Oesterreichische Nationalbank (OeNB), Otto-Wagner-Platz 3, A-1090 Vienna, Austria. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Eurosystem or the OeNB.

Non-Technical Summary

Productivity growth is a key determinant of firms' competitiveness and of long-term economic growth. While monetary policy is primarily aimed at maintaining price stability, changes in interest rates can also influence firms' longer-term productive capacity. Lower interest rates reduce financing costs and can make it easier for firms to invest not only in physical capital, but also in activities that improve productivity, such as new technologies, organizational improvements, and more efficient production processes. These effects may be particularly important for firms that face difficulties in obtaining external finance.

This paper examines how monetary policy affects the productivity of Austrian firms and how firms' financial conditions shape this relationship. We combine a theoretical model with detailed firm-level data covering Austrian non-financial corporations from 2008 to 2018. The model highlights two ways in which monetary policy can affect firms' investment decisions. Interest rates directly influence the cost of financing investment, while changes in financing conditions can have an additional effect on firms that are constrained in how much they can borrow.

Our empirical results show that tighter monetary policy is associated with lower firm-level total factor productivity. The effects are particularly pronounced when changes in monetary policy are persistent. By contrast, unexpected monetary policy changes around central bank announcements have smaller and less robust effects. This suggests that firms' productivity-enhancing investment decisions respond more strongly to sustained changes in financing conditions than to short-lived monetary policy surprises.

Financial conditions also matter for how strongly firms respond to monetary policy. In particular, firms with higher leverage experience larger declines in productivity when monetary policy tightens. This finding is consistent with the idea that financial constraints amplify the transmission of monetary policy: when financing becomes more expensive, highly indebted firms have less scope to undertake investments that could improve their productivity.

Finally, the paper distinguishes between productivity improvements within individual firms and productivity developments in the economy as a whole. Our results indicate that higher productivity at the firm level does not necessarily translate one-for-one into higher aggregate productivity. Changes in how economic activity is distributed across more and less productive firms also matter. This highlights a broader implication of our analysis: monetary policy can influence long-term economic performance not only through its well-known effects on demand and inflation but also through firms' financing conditions, investment decisions, and productivity.

1. Introduction

Aggregate productivity depends both on productivity improvements within firms and on the allocation of economic resources across firms. Monetary policy can affect both margins. Lower interest rates reduce financing costs and relax borrowing constraints, encouraging firms to invest in R&D, technology adoption, and other productivity-enhancing activities. At the same time, monetary policy can alter the allocation of resources across firms. Its aggregate productivity effects therefore depend on both the within-firm productivity response and changes in allocative efficiency.

In the presence of financial frictions, however, the aggregate productivity effects of monetary policy are theoretically ambiguous. Lower interest rates may enable financially constrained firms to undertake productive investments, but they may also weaken market selection. Persistently accommodative monetary policy can reduce banks' incentives to restructure distressed borrowers and allow inefficient "zombie" firms to survive ([Adalet McGowan et al., 2018](#); [Banerjee and Hofmann, 2018](#); [Caballero et al., 2008](#)). Moreover, banks may direct credit toward collateral-rich but less productive firms, while young and innovative firms remain financially constrained ([Buera and Shin, 2013](#); [Caggese et al., 2019](#); [Elfsbacka Schmöller et al., 2025](#); [Gopinath et al., 2017](#); [Midrigan and Xu, 2014](#)). Monetary policy may therefore increase productivity within individual firms while simultaneously reducing aggregate productivity through a deterioration in allocative efficiency. Whether and through which channels monetary policy affects firm-level and aggregate productivity remains an open empirical question.

A growing theoretical and empirical literature studies the relationship between monetary policy, innovation, resource allocation, and total factor productivity (TFP) ([Anzoategui et al., 2019](#); [Benhabib et al., 2012](#); [Bianchi et al., 2019](#); [Comin and Gertler, 2006](#); [Elfsbacka Schmöller and Spitzer, 2022](#); [González et al., 2024](#); [Moran and Queralto, 2018](#)). Much of this literature relies on macroeconomic models with endogenous growth, in which the demand-side forces driving business-cycle fluctuations also influence long-run productivity. This work identifies several channels through which accommodative monetary policy can support productivity growth, including lower capital costs, greater R&D investment, faster technology diffusion, and improved intertemporal resource allocation.

A related literature emphasizes the role of financial frictions in constraining firms' investments in innovation and productivity. Firms facing credit constraints or high external financing costs tend to exhibit significantly lower TFP ([Duval et al., 2020](#); [Ferrando and Ruggieri, 2018](#); [Levine and Warusawitharana, 2021](#)). Existing theoretical frameworks, however, generally examine monetary policy and productivity-enhancing investment separately. [Levine and Warusawitharana \(2021\)](#) model financial frictions that constrain firm-level investment in both capital and productivity but abstract from monetary policy. Conversely, [Jones \(2003\)](#) incorporate monetary policy into the firm's dynamic decision problem but abstract from endogenous investment in productivity. As a result, less is known about how monetary policy and financial constraints jointly shape firm-level TFP, and whether improvements in firm productivity translate into higher aggregate productivity once changes in resource allocation are taken into account.

This paper addresses this gap by combining a dynamic model of firm behavior with a causal empirical analysis of Austrian firms. We develop a dynamic optimization model in which financially constrained firms choose investment in both physical capital and productivity. Cash-

in-advance and collateral constraints allow monetary policy to affect these decisions through firms' financing conditions. Monetary policy and aggregate macroeconomic conditions are treated as exogenous to the individual firm, permitting us to focus on firm-level responses without imposing market-clearing conditions or feedback from individual firms to economic aggregates.

Guided by the model, we estimate the causal effects of monetary policy on firm-level TFP using structural causal models represented by directed acyclic graphs (DAGs), panel fixed-effects estimation, and formal sensitivity analysis.² This framework enables us to distinguish between direct and total monetary policy effects and to assess how strongly omitted confounding would have to influence both monetary policy and firm productivity to overturn our conclusions.

Our empirical analysis distinguishes three complementary dimensions of monetary policy. The ECB policy rate captures the level of financing conditions faced by firms. Deviations of the euro-area policy rate from country-specific Taylor rules capture persistent discretionary departures from systematic monetary policy after accounting for macroeconomic fundamentals such as inflation, output growth, and energy prices (Taylor, 1993, 1999; Woodford, 1999; Rudebusch, 2002; Orphanides and Williams, 2008, 2013). High-frequency monetary policy shocks identified around ECB policy announcements capture transitory and unexpected policy innovations after separating the central-bank information component (Altavilla et al., 2019; Jarocinski and Karadi, 2020). This distinction allows us to investigate whether firms respond differently to realized financing conditions, persistent changes in the monetary policy stance, and short-lived announcement surprises.

The paper makes four contributions. First, we integrate monetary policy, financial constraints, and productivity-enhancing investment within a unified dynamic model of the firm, thereby extending both Jones (2003) and Levine and Warusawitharana (2021). The model clarifies how monetary policy affects firm-level TFP through financing constraints and provides theoretical guidance for the empirical analysis.

Second, we provide a causal identification strategy based on DAGs, do-calculus, and formal sensitivity analysis. The approach makes the identifying assumptions explicit, distinguishes direct from total monetary policy effects, and quantifies the robustness of the estimates to omitted aggregate confounding. It therefore goes beyond a purely associative interpretation of the relationship between monetary policy and firm productivity, an important concern raised by Durante et al. (2022).

Third, we compare the productivity effects of three conceptually distinct dimensions of monetary policy: the level of the policy rate, persistent discretionary deviations from systematic policy, and transitory high-frequency policy surprises. This comparison is important because firm-level investments in productivity are long-term decisions and may respond more strongly to persistent financing conditions than to short-lived policy innovations.

²Although DAG-based causal inference has become standard in many fields outside economics (Pearl, 2009), its application in empirical corporate finance and monetary economics remains relatively rare. The DAG framework makes the assumed causal structure explicit and provides transparent guidance on which variables should and should not be included as controls (Cinelli et al., 2024). In particular, it distinguishes valid controls that block backdoor confounding paths from “bad controls” that block causal transmission channels or induce collider bias.

Fourth, we connect the firm-level estimates to aggregate productivity using the Olley-Pakes decomposition ([Olley and Pakes, 1996](#)). This allows us to separate changes in average firm-level productivity from changes in allocative efficiency and to determine whether productivity gains within firms translate one-for-one into higher aggregate productivity.

Our empirical results show that contractionary monetary policy significantly reduces firm-level TFP. The largest and most robust effects are associated with persistent dimensions of monetary policy, namely the policy rate and discretionary monetary policy measured by deviations from Taylor rules. By contrast, high-frequency announcement surprises have smaller and generally less robust effects. These findings are consistent with the hypothesis that firms' productivity-enhancing investments respond primarily to sustained changes in financing conditions rather than to transitory policy surprises.

The sensitivity analysis shows that the estimated effects of Taylor-rule deviations are highly robust to omitted aggregate confounding, whereas those of high-frequency monetary policy shocks are considerably more sensitive. This difference may reflect the distinct variation captured by the two measures: Taylor-rule deviations identify persistent departures from systematic policy and may therefore be more closely aligned with firms' medium- and long-term productivity decisions, whereas high-frequency shocks capture transitory announcement-induced innovations. Moreover, although our high-frequency measure separates monetary policy shocks from central-bank information shocks following [Jarocinski and Karadi \(2020\)](#), its estimated effects remain sensitive to macroeconomic controls. While this sensitivity does not necessarily imply residual information contamination, it is consistent with broader concerns about the difficulty of isolating pure policy innovations using high-frequency instruments ([Miranda-Agrippino and Ricco, 2021](#)).

Finally, the Olley-Pakes decomposition shows that improvements in average firm-level productivity are partly offset by declining allocative efficiency. Monetary policy therefore affects aggregate productivity through two distinct margins. Those are changes in productivity within firms and changes in the allocation of economic activity across firms. This result helps reconcile positive firm-level productivity effects with more muted aggregate productivity responses and underlines the importance of considering financial frictions and resource reallocation jointly.

The remainder of the paper is structured as follows. Section 2 presents the firm's dynamic optimization problem and derives the effects of policy rates, deviations from monetary policy rules, monetary policy shocks, and financial frictions on firm-level TFP. Section 3 describes the data. Section 4 presents the empirical and causal identification strategies. Section 5 reports the empirical results. Section 6 concludes.

2. How do Financial Frictions and Monetary Policy Influence TFP

This section develops a dynamic firm model to study how monetary policy interacts with financial frictions in shaping firm-level TFP. The framework builds on the dynamic investment models of [Jones \(2003\)](#), the borrowing-constraint framework of [Khan and Thomas \(2013\)](#), and the analysis of productivity-enhancing investment under financial frictions in [Levine and Warusawitharana \(2021\)](#). We extend these approaches by introducing monetary policy directly into firms' financing and investment decisions through the cost of external finance and endogenous borrowing capacity.

Relative to [Levine and Warusawitharana \(2021\)](#), the key extension of our framework is the explicit introduction of an interest-rate channel and borrowing constraints. Monetary policy, therefore, affects firm-level productivity through its impact on financing conditions, borrowing capacity, and the allocation of resources between physical capital accumulation and productivity-enhancing investment. The model is presented in a self-contained way such that familiarity with the underlying papers is not required for understanding the mechanisms developed below.

2.1. Economic Environment

Time is discrete and indexed by $t = 0, 1, 2, \dots$. At the beginning of period t , the firm enters with equity e_t . After paying fixed operating costs and dividends, it retains post-dividend equity $\tilde{e}_t$. The firm then chooses labor l_t , physical capital k_t , and productivity-enhancing investment s_t . Production takes place, debt is repaid, and next-period equity e_{t+1} is determined. The firm discounts future payouts at a rate $\beta \in (0, 1)$.

The firm's production, financing, and borrowing environment is described by:

$$e_{t+1} = (1 - \delta)\tilde{e}_t + \rho_t(s_t) k_t^\alpha l_t^{1-\alpha} - (1 + r_t)b_t, \quad (1a)$$

$$\tilde{e}_t = e_t - C - d_t, \quad (1b)$$

$$b_t = w l_t + r_{k,t}(k_t + s_t - \tilde{e}_t), \quad (1c)$$

$$r_{k,t} = r_t + \delta, \quad (1d)$$

$$d_t \geq 0, \quad (1e)$$

$$0 \leq b_t \leq \chi_t \tilde{e}_t, \quad (1f)$$

$$\chi_t = \varphi \frac{1 - \delta}{1 + r_t}, \quad (1g)$$

$$r_t = \bar{r} + \zeta(r_{t-1} - \bar{r}) + \epsilon_t^{MPS}. \quad (1h)$$

Eq. (1a) is the equity transition equation. Here, $\delta \in [0, 1)$ denotes the depreciation rate, k_t is the firm's physical capital stock, l_t denotes labor input, and $\rho_t(s_t)$ captures the firm's production efficiency as a function of productivity-enhancing investment s_t . Following [Levine and Warusawitharana \(2021\)](#), we assume that productivity-enhancing investment improves the efficiency with which capital and labor are transformed into output. Accordingly, the production-efficiency function satisfies $\rho'(s_t) > 0$ and $\rho''(s_t) < 0$, implying positive but diminishing marginal returns to productivity-enhancing investment.

Productivity-enhancing investment requires financing at the same cost as physical capital. As in [Jones \(2003\)](#), firms choose labor l_t , physical capital k_t , and productivity-enhancing investment s_t before an idiosyncratic productivity shock ω_t is realized within period t . Realized production efficiency is therefore given by $\rho_t(s_t, \omega_t)$. To keep the notation compact, we suppress the dependence on ω_t in the derivations below and write $\rho_t(s_t)$ when referring to expected production efficiency conditional on the firm's information set at the time decisions are made. The dynamic structure of the model arises from firms' intertemporal financing and equity accumulation decisions rather than from a persistent productivity stock.

Eq. (1b) defines post-dividend equity. The firm enters period t with equity e_t , pays fixed oper-

ating costs C , distributes dividends d_t , and retains $\tilde{e}_t$ for financing production and investment.

Eq. (1c) describes the firm's financing requirement. The variable b_t denotes one-period external borrowing. Firms finance production and investment using retained equity and external debt. Retained equity is used to finance investment expenditures, while any remaining financing requirement is covered through external borrowing. The cost of capital is given by $r_{k,t} = r_t + \delta$, as in Cooley and Quadrini (2006). We assume that labor, capital, and productivity-enhancing investment are chosen before idiosyncratic uncertainty is realized, so financing decisions must be made under uncertainty.

Eq. (1e) imposes a non-negativity constraint on dividends, implying that firms cannot issue new equity. Eq. (1f) introduces a borrowing limit, where the collateral parameter χ_t depends negatively on the policy rate through Eq. (1g). Hence, tighter monetary policy reduces the amount that firms can borrow against retained equity:

$$\frac{\partial \chi_t}{\partial r_t} < 0.$$

The parameter $\varphi > 0$ captures the pledgeability of firm assets. A higher φ relaxes the borrowing constraint by allowing firms to pledge a larger fraction of retained equity.

Eq. (1h) introduces monetary policy through an exogenous process for the policy rate. We assume that the policy rate follows this autoregressive process, where $\bar{r}$ denotes the long-run benchmark policy rate, $\zeta \in (0, 1)$ captures the persistence of monetary policy, and ϵ_t^{MPS} denotes an unexpected monetary policy innovation.³

The decomposition naturally distinguishes three conceptually different dimensions of monetary policy. First, the observed policy rate r_t determines firms' financing costs directly and therefore captures the overall financing conditions entering the firm's optimization problem. Second, deviations of the observed policy rate from the benchmark policy rate implied by macroeconomic fundamentals measure the discretionary monetary policy stance. These deviations represent persistent departures from systematic monetary policy and are therefore particularly relevant for firms' long-term investment decisions. Third, the innovation ϵ_t^{MPS} captures unexpected monetary policy announcements that shift financing conditions independently of the systematic component of the policy. Empirically, these innovations are commonly approximated using high-frequency monetary policy surprises identified around central bank announcements. Our empirical analysis separately examines these three measures to distinguish between the effects of financing costs, discretionary monetary policy, and unexpected monetary policy innovations on firm-level productivity.

In our firm-level framework, we abstract from general equilibrium feedback and treat the resulting interest-rate process as exogenous to individual firms—which is adequate given that we study Austrian firms and the policy rate is set for the whole euro area—while maintaining the distinction between policy stance and monetary policy shocks that is central to the empirical analysis.

³This reduced-form representation can be interpreted as a simplified version of a standard Taylor-type policy rule, $r_t = \zeta r_{t-1} + (1 - \zeta)(\phi_\pi \pi_t + \phi_y y_t) + \epsilon_t^{MPS}$, where inflation and real activity determine the systematic component of monetary policy. In this interpretation, the benchmark policy rate is the policy rate implied by macroeconomic fundamentals.

2.2. Dynamic Firm Optimization

The firm's objective is to maximize the expected discounted stream of dividends. Since dividends are linked to retained equity through the accounting identity

$$d_t = e_t - C - \tilde{e}_t,$$

they can be eliminated from the optimization problem. We allow the firm to liquidate irreversibly whenever continued operation is infeasible or yields a lower value.⁴ Conditional on continued operation, the firm's dynamic optimization problem can therefore be written as

$$\begin{aligned} V = \max_{\{\tilde{e}_t, k_t, l_t, s_t\}_{t=0}^{\infty}} \quad & \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t (e_t - C - \tilde{e}_t) \\ \text{s.t.} \quad & \text{Eqs. (1a)–(1h).} \end{aligned} \tag{2}$$

Conditional on continued operation, the firm's problem is a dynamic optimization problem with borrowing constraints and nonlinearities. Optimality also requires the standard transversality condition $\lim_{T \rightarrow \infty} \beta^T \lambda_T e_{T+1} = 0$.

While the structure is standard, the presence of occasionally binding constraints implies that closed-form policy functions are generally not available, and the model must be analyzed using its implied optimality conditions and transition equations. The formal existence result and proof are reported in [Appendix A](#).

To characterize the firm's choices, let $\kappa_t \geq 0$ denote the multiplier on the dividend constraint, $\psi_t \geq 0$ the multiplier on the borrowing constraint, and λ_t the multiplier on the equity transition equation. After substituting the financing identity for b_t , the Lagrangian is

$$\begin{aligned} \mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Big\{ & (e_t - C - \tilde{e}_t) \\ & + \lambda_t \left[(1 - \delta)\tilde{e}_t + \rho_t(s_t)k_t^\alpha l_t^{1-\alpha} \right. \\ & \quad \left. - (1 + r_t)(wl_t + r_{k,t}(k_t + s_t - \tilde{e}_t)) - e_{t+1} \right] \\ & + \psi_t \left[\chi_t \tilde{e}_t - (wl_t + r_{k,t}(k_t + s_t - \tilde{e}_t)) \right] \\ & + \eta_t \left[wl_t + r_{k,t}(k_t + s_t - \tilde{e}_t) \right] \\ & \left. + \kappa_t (e_t - C - \tilde{e}_t) \right\}. \end{aligned} \tag{3}$$

⁴Upon liquidation, the firm distributes its remaining equity, exits permanently, and enters an absorbing state with zero continuation value. This option guarantees that the feasible action set is nonempty at every state and does not affect the first-order conditions for firms that continue operating. This treatment follows [Jones \(2003\)](#).

The first-order conditions for the intra-period choices are

$$\frac{\partial \mathcal{L}}{\partial l_t} = -\psi_t w + \eta_t w + \lambda_t \rho_t(s_t) k_t^\alpha (1 - \alpha) l_t^{1-\alpha} - \lambda_t (1 + r_t) w = 0, \quad (4a)$$

$$\frac{\partial \mathcal{L}}{\partial k_t} = -\psi_t r_{k,t} + \eta_t r_{k,t} + \lambda_t \rho_t(s_t) \alpha k_t^{\alpha-1} l_t^{1-\alpha} - \lambda_t (1 + r_t) r_{k,t} = 0, \quad (4b)$$

$$\frac{\partial \mathcal{L}}{\partial s_t} = -\psi_t r_{k,t} + \eta_t r_{k,t} + \lambda_t k_t^\alpha l_t^{1-\alpha} \rho'_t(s_t) - \lambda_t (1 + r_t) r_{k,t} = 0, \quad (4c)$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial \tilde{e}_t} = & -(1 + \kappa_t) + \psi_t (\chi_t + r_{k,t}) - \eta_t r_{k,t} \\ & + \lambda_t [(1 - \delta) + (1 + r_t) r_{k,t}] = 0. \end{aligned} \quad (4d)$$

together with the complementary slackness conditions

$$\psi_t \geq 0, \quad \chi_t \tilde{e}_t - b_t \geq 0, \quad \psi_t (\chi_t \tilde{e}_t - b_t) = 0, \quad (5)$$

$$\eta_t \geq 0, \quad b_t \geq 0, \quad \eta_t b_t = 0, \quad (6)$$

$$\kappa_t \geq 0, \quad e_t - C - \tilde{e}_t \geq 0, \quad \kappa_t (e_t - C - \tilde{e}_t) = 0. \quad (7)$$

These optimality conditions highlight the central transmission mechanism of the model. Higher interest rates increase financing costs directly through the user cost of capital and indirectly by tightening the borrowing constraint via χ_t . Both channels reduce the profitability of physical capital and productivity-enhancing investment, thereby lowering firm-level productivity.

2.3. Binding versus non-binding financial constraints

When the upper borrowing constraint binds and the firm borrows a positive amount,

$$b_t = \chi_t \tilde{e}_t > 0.$$

Complementary slackness then implies $\psi_t > 0$ and $\eta_t = 0$. Combining the binding borrowing constraint with the financing equation,

$$b_t = w l_t + r_{k,t} (k_t + s_t - \tilde{e}_t),$$

gives

$$\tilde{e}_t = \frac{w l_t + r_{k,t} (k_t + s_t)}{\chi_t + r_{k,t}}.$$

Substituting this expression, together with $b_t = \chi_t \tilde{e}_t$, into the equity transition equation yields

$$e_{t+1} = (1 - \delta) \frac{wl_t + r_{k,t}(k_t + s_t)}{\chi_t + r_{k,t}} + \rho_t(s_t)k_t^\alpha l_t^{1-\alpha} - (1 + r_t) \frac{\chi_t [wl_t + r_{k,t}(k_t + s_t)]}{\chi_t + r_{k,t}}. \quad (8)$$

In this regime, the first-order condition for post-dividend equity becomes

$$1 + \kappa_t = \psi_t(\chi_t + r_{k,t}) + \lambda_t [(1 - \delta) + (1 + r_t)r_{k,t}]. \quad (9)$$

The shadow value ψ_t captures the additional value of retained equity arising from its role in relaxing the binding upper borrowing constraint.

If the upper borrowing constraint does not bind, then $\psi_t = 0$. Two cases must be distinguished. First, if borrowing is strictly positive,

$$0 < b_t < \chi_t \tilde{e}_t,$$

then neither borrowing bound binds and

$$\psi_t = \eta_t = 0.$$

Next-period equity evolves according to

$$e_{t+1} = (1 - \delta)\tilde{e}_t + \rho_t(s_t)k_t^\alpha l_t^{1-\alpha} - (1 + r_t)b_t. \quad (10)$$

The retained-equity first-order condition becomes

$$1 + \kappa_t = \lambda_t [(1 - \delta) + (1 + r_t)r_{k,t}]. \quad (11)$$

If the dividend constraint is also non-binding, so that $\kappa_t = 0$, this condition implies

$$\lambda_t = \frac{1}{(1 - \delta) + (1 + r_t)r_{k,t}}. \quad (12)$$

Second, the lower borrowing constraint may bind:

$$b_t = 0, \quad \eta_t > 0, \quad \psi_t = 0.$$

In this no-borrowing regime, the retained-equity first-order condition is

$$1 + \kappa_t = -\eta_t r_{k,t} + \lambda_t [(1 - \delta) + (1 + r_t)r_{k,t}]. \quad (13)$$

The multiplier η_t captures the shadow value of relaxing the non-negativity constraint on external borrowing.

Equations (8) and (10) describe the evolution of firm equity when the upper borrowing constraint binds and when borrowing is interior, respectively. Productivity-enhancing investment raises output through $\rho_t(s_t)$, but it must also be financed and therefore increases the financing requirement through $r_{k,t}s_t$. Its net effect on future equity depends on its productivity return relative to the associated financing cost.

Monetary tightening affects firms with positive borrowing by raising the user cost of capital and the cost of external finance. When the upper borrowing constraint binds, these effects are amplified because tighter monetary policy also reduces borrowing capacity through χ_t , increasing the shadow value of retained equity. In the no-borrowing regime, by contrast, the lower bound on debt becomes relevant and the firm's response is characterized by the multiplier η_t .

Because the model contains nonlinearities and occasionally binding upper and lower borrowing constraints, analytical policy functions for the optimal choices $(k_t, l_t, s_t, \tilde{e}_t)$ are generally not available. Instead, the model is characterized by its equilibrium first-order conditions together with the state-transition equation. We therefore use these optimality conditions to derive qualitative predictions concerning the sign and heterogeneity of the relationship between monetary policy and firm-level TFP.

2.4. Comparative Statics and Empirical Predictions

The model does not admit closed-form policy functions because firms jointly choose physical capital, labor, productivity-enhancing investment, and retained equity subject to occasionally binding upper and lower borrowing constraints. Consequently, we derive qualitative comparative-static predictions from the optimality conditions rather than from closed-form decision rules.

The first-order conditions for physical capital and productivity-enhancing investment imply

$$\underbrace{\lambda_t \rho_t(s_t) \alpha k_t^{\alpha-1} l_t^{1-\alpha}}_{\text{Marginal benefit of physical capital}} = \underbrace{r_{k,t} \lambda_t (1 + r_t)}_{\text{Direct financing cost}} + \underbrace{r_{k,t} \psi_t}_{\text{Cost of the binding upper borrowing limit}} - \underbrace{r_{k,t} \eta_t}_{\text{Effect of the binding lower borrowing limit}}, \quad (14)$$

$$\underbrace{\lambda_t k_t^\alpha l_t^{1-\alpha} \rho'_t(s_t)}_{\text{Marginal benefit of productivity investment}} = \underbrace{r_{k,t} \lambda_t (1 + r_t)}_{\text{Direct financing cost}} + \underbrace{r_{k,t} \psi_t}_{\text{Cost of the binding upper borrowing limit}} - \underbrace{r_{k,t} \eta_t}_{\text{Effect of the binding lower borrowing limit}}. \quad (15)$$

Both optimality conditions equate the marginal benefit of investment to its effective marginal financing cost. The multiplier $\psi_t \geq 0$ is associated with the upper borrowing constraint,

$$b_t \leq \chi_t \tilde{e}_t,$$

whereas $\eta_t \geq 0$ is associated with the lower borrowing constraint,

$$b_t \geq 0.$$

The two multipliers therefore represent economically distinct regimes.

For firms with positive borrowing, $b_t > 0$, complementary slackness implies $\eta_t = 0$. In this empirically central case, monetary policy affects investment through two channels. First, a higher policy rate raises the user cost of capital, $r_{k,t} = r_t + \delta$, and the repayment cost of external debt. Second, if the upper borrowing constraint binds, monetary tightening reduces borrowing capacity through χ_t and raises the shadow value of external finance, ψ_t . Both channels increase the effective marginal cost of physical capital and productivity-enhancing investment.

Three borrowing regimes can be distinguished:

1. If $0 < b_t < \chi_t \tilde{e}_t$, neither borrowing bound binds and $\psi_t = \eta_t = 0$. Monetary policy affects investment through the direct financing-cost channel.
2. If $b_t = \chi_t \tilde{e}_t > 0$ the upper borrowing constraint binds, so that $\psi_t > 0$, $\eta_t = 0$. The direct financing-cost effect is then amplified by the shadow cost of the borrowing limit.
3. If $b_t = 0$, the lower borrowing constraint may bind, so that $\eta_t > 0$, $\psi_t = 0$, provided the upper borrowing limit is slack. This regime describes a firm that does not use external debt and is therefore distinct from the borrowing-constrained regime emphasized in the empirical analysis.

The model's financial-friction amplification mechanism concerns the second regime. When the upper borrowing constraint binds, retained earnings become more valuable because they expand borrowing capacity, while tighter monetary policy simultaneously raises financing costs and reduces the amount that the firm can borrow. Financially constrained borrowers therefore reduce physical capital and productivity-enhancing investment more strongly than otherwise comparable firms with slack upper borrowing constraints.

The empirical analysis focuses on this amplification mechanism. Because the econometric specifications include firm fixed effects, permanent differences in average productivity—including those arising from persistent financing conditions—are absorbed by the fixed effects. Identification therefore relies on within-firm variation over time and tests whether firms with indicators of tighter financial constraints respond more strongly to changes in monetary policy.

The theoretical framework naturally distinguishes three conceptually different dimensions of monetary policy; see Eq. (1h). The policy rate enters the firm's optimization problem directly through financing costs and the borrowing constraint. Discretionary monetary policy captures persistent deviations of the observed policy rate from its rule-based benchmark and therefore measures sustained changes in financing conditions. Monetary policy shocks represent unexpected innovations around the expected policy path and capture transitory changes in financing conditions. These measures should not be viewed as competing representations of monetary policy. Rather, discretionary monetary policy and monetary policy shocks are both defined relative to the underlying policy-rate process and complement the direct effect of the policy rate itself.

Taken together, the model yields two theoretical predictions and one empirically testable implication:

1. Tighter monetary policy reduces firms' investment in productivity-enhancing activities by increasing financing costs.
2. Among firms that use external borrowing, a binding upper borrowing constraint amplifies the effect of monetary policy because constrained firms experience an increase in the shadow value of external finance when financing conditions tighten.
3. The model provides an economic rationale for expecting persistent changes in the monetary policy stance to have larger effects on firm-level productivity than temporary monetary policy shocks. Because firms' investment decisions are forward-looking, they are likely to respond more strongly to sustained changes in financing conditions than to short-lived policy surprises. Whether this persistence ranking holds quantitatively is ultimately an empirical question.

3. Data

In our empirical application, we analyze the determinants of total factor productivity using firm-level data as well as macroeconomic variables. Our microdata encompass around 57,000 observations for 14,500 firms located in Austria and span the period from 2008 to 2018 on a yearly basis. Collected by the Oesterreichische Nationalbank (OeNB) to determine Inhouse Credit Assessment ratings, the data include annual financial statements of non-financial corporations (i.e., sector 11 according to the European System of Accounts) in Austria.

Importantly, the sample is not limited to credit claims from firms with sufficiently high credit-worthiness.⁵ The information is collected from the Austrian public commercial register as well as from banks and firms themselves to extend to a more granular level. Since small firms often do not provide data in sufficient granularity to determine all necessary indicators, they may be underrepresented in our analysis. Moreover, we do not consider any holding companies (NACE-group 64.2) or head offices (NACE-group 70.1) as their scope of economic activity is rather distinct.

We extend firm-level microdata with information on interest rates as well as the Austrian macroeconomic environment. We include GDP growth, core inflation (HICP excluding food and energy), and the synthetic energy indicator, all measured as year-on-year rates of change and taken from the ECB's Statistical Data Warehouse. The synthetic energy indicator is constructed as a weighted average of oil and gas price developments using net import weights, with weights of approximately 60% for oil and 40% for gas. For the interest rate, we choose the deposit facility rate (DFR) provided by the ECB (Statistical Data Warehouse). Moreover, we take the yield curve of the government zero coupon bond yields (IYC 10 years) for Austria from Bloomberg.

Table 1 presents the summary statistics of all variables included. A detailed variable description is given in the subsections below.

⁵ Around 60% of credit claims in our sample exhibit a one-year probability of default above 0.4% and, therefore, do not meet the eligibility criteria for monetary policy operations. According to Credit Quality Step 3, which is the minimum requirement of credit assessment on the Eurosystem's harmonized rating scale to be accepted as eligible collateral, the probability of default must not exceed 0.40%. For more details, see <https://www.ecb.europa.eu/paym/coll/risk/ecaf/html/index.en.html>.

Table 1: Summary statistics of included variables

	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Data.Cov
1) Dependent Variable: Total Factor Productivity							
TFP (Firm FE)	-3.17	3.44	3.85	3.86	4.23	8.31	88.92
TFP (ACF)	-3.62	2.81	3.16	3.20	3.52	7.57	88.93
2) Explanatory Variables:							
2A) Firm-level data							
Leverage	0.00	3.19	23.32	28.50	45.45	276.16	99.94
Cash holdings	0.00	0.43	2.56	6.99	9.29	58.65	99.14
Interest expense ratio	0.00	1.03	1.78	2.14	2.76	12.92	93.28
External fin. dependence	0.00	11.97	31.55	122.93	112.30	1062.41	92.72
Net investment ratio	-92.49	-5.67	-0.37	2.45	8.55	91.52	97.99
$\Delta(\text{Debt})$ ratio	-100.00	-11.83	-1.22	3.40	12.97	158.90	78.45
Low Default Risk	0.00	0.00	1.00	0.69	1.00	1.00	87.95
2B) Macro variables and interest rates							
HICP core (-1)	1.32	1.68	1.74	1.86	2.14	2.53	100.00
Synthetic Energy (-1)	-54.05	-21.92	1.13	0.01	26.56	36.11	100.00
GDP growth (-1)	-1.92	2.69	3.26	2.93	4.01	6.11	100.00
IYC 10 years	0.07	0.74	2.35	2.24	3.39	4.08	100.00
ECB DFR	-0.43	-0.21	0.13	0.31	0.47	3.01	100.00
2C) Monetary Policy Surprise							
DMP Taylor 1993	-5.28	-3.16	-1.83	-1.92	-1.33	2.94	100.00
DMP Taylor 1999	-4.82	-3.36	-2.30	-1.76	-0.96	3.51	100.00
DMP First difference rule	-2.89	-0.89	-0.22	-0.04	1.85	2.56	100.00
High-Freq. static MPS	-3.82	-1.67	3.04	4.54	7.94	22.27	100.00
High-Freq. dynamic MPS	-4.24	-0.46	2.81	4.86	5.57	29.26	100.00

Data sources: OeNB, Austrian Commercial Register, ECB SDW, Eurostat, Bloomberg.

The table shows the minimum (Min.), the first quantile (1st Qu.), the median (Median), the mean (Mean), the third quantile (3rd Qu.), the maximum (Max) and the data coverage (Data Cov.) for the variables used in this paper. Data Cov. refers to the percentage of available observations if the data was a balanced panel.

We only include firms that at least report three times in the period 2008–2018. This leaves us with 57,662 available observations between 2008 and 2018. The number of firms is 14,535.

TFP (Firm FE) is the estimated using the fixed effects model as in [Ernst and Sigmund \(2023\)](#). TFP (ACF) is estimated by the method suggested in [Akerberg et al. \(2015\)](#). Definitions of the firm-level variables are provided in Section 3.1.

DMP measures monetary policy deviations based on the [Taylor \(1993\)](#), [Taylor \(1999\)](#), and first-difference rules as defined in Section 3.3. High-frequency MPS measures follow [Jarocinski and Karadi \(2020\)](#); the dynamic version uses a 12-month rolling window.

3.1. Total Factor Productivity and Profitability

Our theoretical model predicts that monetary policy affects firms' TFP, represented by ρ in the model. We therefore require a firm-level measure of productivity that is comparable across firms and over time. To estimate TFP, we use firm-level information on output, labor, capital, and intermediate inputs obtained from annual financial statements.

Following [Ernst and Sigmund \(2023\)](#), our preferred measure of TFP is based on a panel-data fixed-effects estimator of the production function. In their comparison of alternative productivity estimators, the fixed-effects approach achieves the lowest root mean squared prediction error and outperforms a range of widely used methods in the productivity literature.⁶ We therefore use the resulting firm-level fixed-effects TFP estimates as our baseline productivity measure. As a robustness check, we additionally estimate TFP using the semiparametric approach of

⁶The comparison includes, among others, the estimators proposed by [Olley and Pakes \(1996\)](#), [Levinsohn and Petrin \(2003\)](#), [Akerberg et al. \(2015\)](#), [Wooldridge \(2009\)](#), [Solow \(1957\)](#), and [Blundell and Bond \(1998\)](#).

[Akerberg et al. \(2015\)](#).

Output is measured by firms' total revenues, labor input by staff expenses, and intermediate inputs by material costs, all obtained from firms' profit and loss statements. Capital is measured as the sum of tangible and intangible fixed assets reported on the balance sheet. This measure captures both physical capital, such as machinery and buildings, and intangible capital, including software, patents, and licenses.

3.2. Empirical Proxies for Financial Constraints

We consider seven proxies for financial constraints. Leverage captures balance-sheet risk and proximity to borrowing constraints. Cash holdings measure internal liquidity. The interest expense ratio reflects the effective cost of debt financing. External finance dependence captures firms' reliance on outside financing. The net investment ratio reflects realized investment activity. Debt growth measures changes in borrowing. Finally, low default risk identifies firms with relatively high credit quality

First, we measure leverage as interest-bearing book debt divided by total assets ([Levine and Warusawitharana, 2021](#)). Firms with higher leverage typically face higher borrowing costs because their probability of financial distress is greater (e.g., [Leland, 1994](#); [Whited and Wu, 2006](#); [Hennessy and Whited, 2007](#)). Moreover, leverage captures the proximity of firms to collateral or borrowing constraints, implying that the shadow cost of external funds increases as firms approach their borrowing limit ([Kiyotaki and Moore, 1997](#)).

Second, we consider cash holdings, measured as cash and cash equivalents divided by total assets. Firms with larger liquidity buffers can finance investment internally and are therefore less dependent on external capital markets. Higher cash holdings may also improve firms' creditworthiness and reduce the cost of external financing.

Third, we use the interest expense ratio, defined as interest expenses divided by interest-bearing debt. This variable reflects the effective cost of debt financing faced by a firm. Higher interest expenses may indicate less favorable borrowing conditions, tighter financing constraints, and lower internal resources available for productive investment.

Fourth, we employ a proxy for external finance dependence, measured as the ratio of fixed assets to total revenue. Firms with a high share of fixed assets relative to sales typically require substantial long-term financing and are therefore expected to rely more heavily on external sources of funding. Consequently, these firms may be more exposed to changes in financing conditions induced by monetary policy.

Fifth, following [Ferrando and Ruggieri \(2018\)](#), we include the net investment ratio, defined as the annual change in fixed assets relative to the stock of fixed assets. Financially constrained firms are generally less able to undertake new investment, implying that lower investment rates are indicative of tighter financing constraints.

Sixth, we include the annual growth rate of total liabilities, denoted by $\Delta(\text{Debt})$. This variable captures changes in firms' borrowing behavior. A decline in debt growth may reflect reduced credit supply, weaker credit demand, or tighter financing constraints, whereas rapid debt growth indicates easier access to external finance.

Finally, we use firms' default risk as an additional proxy for financing conditions. We define low default risk as a binary indicator equal to one if the firm's one-year probability of default is below 1%. Lower default risk increases the credit quality of loans to these firms and may improve banks' willingness to provide financing. Consequently, low-default-risk firms are likely to face more favorable borrowing conditions and less stringent financial constraints than otherwise similar firms.

3.3. Empirical Measure of Monetary Policy Stance

The theoretical model in Section 2 distinguishes between persistent financing conditions and unexpected monetary policy innovations (Eq. (1h)). While high-frequency shocks isolate unexpected policy innovations around ECB announcements, Taylor-rule deviations capture persistent departures of the observed policy rate from the level implied by macroeconomic fundamentals.

To construct the monetary policy stance, we measure the observed policy rate by the ECB DFR obtained from the ECB Statistical Data Warehouse. The ECB DFR provides the empirical counterpart to the policy rate in the theoretical model. The benchmark policy rate is approximated by three alternative Taylor-type policy rules based on Austrian macroeconomic fundamentals.

Consistent with the structural causal model in Section 4.1, the benchmark policy rate is not directly observed. We therefore approximate it by the policy rate implied by an estimated Taylor rule, denoted by $\hat{i}_t$. The discretionary monetary policy stance is defined as

$$DMP_t = i_t - \hat{i}_t, \quad (16)$$

where i_t denotes the observed ECB deposit facility rate and $\hat{i}_t$ the policy rate implied by the respective Taylor rule or first-difference rule. Positive values indicate that the observed policy rate exceeds the level implied by macroeconomic fundamentals and therefore correspond to a restrictive monetary policy stance, whereas negative values indicate an accommodative stance. The Taylor-rule deviation should therefore be interpreted as an empirical proxy for the latent discretionary component of monetary policy rather than as the structural policy intervention itself.

As our first benchmark, we employ the original monetary policy rule proposed by Taylor (1993),

$$i_t = r^* + \pi_t + 0.5(\pi_t - \pi^*) + 0.5 \left(\frac{y_t - y_t^*}{y_t^*} \right), \quad (17)$$

where r^* denotes the long-run real neutral interest rate, π_t is inflation, π^* is the inflation target, y_t is real GDP growth, and y_t^* denotes potential output growth. Following Johanssen and Mertens (2016), we set $r^* = 0.4$.

As a second specification, we consider the modified Taylor rule proposed by Taylor (1999),

$$i_t = r^* + \pi_t^{Core} + 0.5(\pi_t^{Core} - \pi^*) + \left(\frac{y_t - y_t^*}{y_t^*} \right). \quad (18)$$

Finally, we consider the first-difference rule suggested by [Orphanides and Williams \(2008, 2013\)](#),

$$i_t = i_{t-1} + 1.74(\pi_{t+3}^F - \pi^*) - 1.19(u_{t-1} - u_{t-2}), \quad (19)$$

which emphasizes inflation forecasts, changes in unemployment, and policy-rate inertia.

Throughout the empirical analysis, the estimated Taylor-rule deviation serves as a proxy for persistent discretionary monetary policy. Unlike high-frequency monetary policy shocks, which capture unexpected policy innovations around ECB announcements, Taylor-rule deviations measure sustained departures of the observed policy rate from the level implied by macroeconomic fundamentals and therefore capture persistent changes in firms' financing conditions.

3.4. Measuring High-Frequency Monetary Policy Shocks

In the theoretical model, the innovation ϵ_t^{MPS} in Eq. (1h) represents an unexpected monetary policy shock that temporarily moves the policy rate away from its expected path. Unlike the monetary policy stance, which captures persistent financing conditions, these innovations reflect unanticipated policy decisions that are orthogonal to the systematic component of monetary policy.

To obtain an empirical counterpart to ϵ_t^{MPS} , we use externally identified high-frequency monetary policy shocks. These shocks are extracted from financial market reactions within narrow windows around ECB policy announcements and are designed to isolate the unexpected component of monetary policy decisions.

High-frequency identification has become the standard approach for measuring unexpected monetary policy innovations (see, e.g., [Altavilla et al., 2019](#); [Jarocinski and Karadi, 2020](#); [Swanson, 2021](#)). The underlying idea is that financial markets adjust almost immediately following monetary policy announcements. Consequently, interest-rate movements within narrow event windows predominantly reflect new information released by the central bank rather than other macroeconomic developments. High-frequency identification, therefore, provides an empirical proxy for unexpected monetary policy innovations.

In particular, we choose the setup of [Jarocinski and Karadi \(2020\)](#), who jointly analyze the movement in interest rates and stock prices around central bank announcements. Since monetary policy decisions are usually communicated alongside an assessment of the economic outlook, the stock market index is used to disentangle monetary policy from central bank information shocks. According to basic economic theory, a monetary policy tightening increases interest rates and lowers stock prices. Co-moving interest rates and stock prices, on the other hand, point towards a tightening accompanied by a positive information shock. Using sign restrictions, [Jarocinski and Karadi \(2020\)](#) separate monetary policy shocks from central bank information shocks, allowing us to employ a measure that is substantially less contaminated by

the information component contained in policy announcements.⁷

Because the theoretical model is formulated at an annual frequency, the monthly shocks must be aggregated before entering the empirical analysis. We consider a dynamic and a static aggregation of the high-frequency instrument. In the static case, we use a weighted average that takes into account the timing of the shock (Albrizio et al., 2023). A monetary policy surprise announced in January only affects the current year, while a shock happening at the end of the year affects both the current year and the following year. The monetary policy shock resulting from the aggregation scheme can be summarized as

$$MPS_{i,t} = \sum_m \omega_0(m)MPS_{m,t-1} + \sum_m \omega_1(m)MPS_{m,t}, \quad \omega_0(m) = \frac{m}{12}, \quad \omega_1(m) = \frac{12-m}{12}. \quad (20)$$

$MPS_{i,t}$ refers to the yearly monetary policy surprise in year t . $MPS_{m,t}$ depicts the high-frequency shock in month $m = 0, \dots, 11$ in year t . For more details, we refer to Albrizio et al. (2023).

For the dynamic aggregation, we accumulate the monthly monetary policy shocks over a rolling 12-month window. This specification summarizes the cumulative unexpected monetary policy innovations affecting firms during the previous year and aligns the high-frequency identification with the annual frequency of the firm-level productivity data. Rather than focusing on the effect of a single monetary policy announcement, the rolling aggregation captures the overall monetary policy environment to which firms are exposed over the preceding twelve months.

This aggregation is motivated by the fact that firms typically adjust investment, financing, and production decisions only gradually. Productivity-enhancing investment often involves planning, financing, and implementation lags, implying that multiple monetary policy surprises occurring throughout the year jointly influence firms' investment decisions. Aggregating the monthly surprises therefore provides a more appropriate measure of the cumulative monetary policy environment than treating each announcement in isolation.

Positive values of the aggregated shock correspond to unexpected monetary policy tightenings, whereas negative values indicate unexpected monetary policy loosening. Unlike the monetary policy stance derived from Taylor-rule deviations, which measures persistent deviations of the policy rate from its systematic component, the high-frequency shocks isolate unexpected policy innovations around the expected policy path. The rolling-window aggregation, therefore, captures the cumulative sequence of these transitory policy surprises over the preceding twelve months rather than a persistent change in the stance of monetary policy.

4. Empirical Approach and Identification

This section translates the theoretical framework into an empirical identification strategy. The model developed in Section 2 predicts that monetary policy affects firm-level TFP through fi-

⁷We use the target shock of Jarocinski and Karadi (2020) publicly available on the author's website.

nancing costs and financial frictions. Because these channels operate simultaneously and monetary policy is determined at the aggregate level whereas productivity is observed at the firm level, identifying the causal effects of monetary policy requires both a causal and a statistical identification strategy.

Because causal identification and statistical identification address different questions, we discuss them separately. The former establishes the conditions under which the causal effects of monetary policy are identified, whereas the latter explains how these effects are estimated using the available panel data.

We proceed in two steps. First, in Section 4.1, we derive the causal identification strategy implied by the theoretical model. We formulate the model as a recursive structural causal model (Pearl, 2009), represent it using DAGs, and use the backdoor criterion and do-calculus to identify the total and direct effects of the policy rate, the monetary policy stance, and monetary policy shocks on firm-level TFP.

Second, we discuss the statistical identification of these causal effects using panel data. We explain how the econometric specifications exploit within-firm variation over time together with common aggregate monetary policy measures to estimate the causal effects implied by the theoretical framework. We then introduce interaction models that test the model's prediction that monetary policy has stronger effects for financially constrained firms.

4.1. Structural causal model implied by the theoretical framework

The dynamic optimization problem developed in Section 2 implies a recursive structural causal model linking monetary policy, financing conditions, firms' investment decisions, and firm-level productivity. Monetary policy is determined at the aggregate level, whereas firms are price takers with respect to the monetary environment and therefore treat monetary policy as exogenous.

At the aggregate level, the realized policy rate evolves according to Eq. (1h).

$$r_t = f_r(r_{t-1}, \bar{r}, \epsilon_t^{MPS}), \quad (21)$$

where $\bar{r}$ denotes the systematic component implied by the central bank's reaction function, and ϵ_t^{MPS} represents an unexpected monetary policy innovation. Conceptually, the central bank first determines the systematic component of monetary policy based on macroeconomic conditions and subsequently sets the realized policy rate. Hence, the latent discretionary component and unexpected monetary policy innovations are upstream determinants of the realized policy rate.

At the firm level, the policy rate determines financing conditions through

$$\chi_t = f_\chi(r_t, \varphi), \quad (22)$$

where φ summarizes collateral-related characteristics. Given financing conditions and firm-specific state variables, firms choose productivity-enhancing investment according to

$$s_{i,t} = f_s(e_{i,t}, r_t, \chi_t, \epsilon_{i,t}^s), \quad (23)$$

where $\epsilon_{i,t}^s$ denotes firm-specific investment shocks. Productivity subsequently evolves as

$$\rho_{i,t} = f_\rho(e_{i,t}, s_{i,t}, \epsilon_{i,t}^\rho). \quad (24)$$

Equations (21)–(24) describe the latent structural causal model implied by the theoretical framework. The monetary policy variables $\bar{r}_t$ and ϵ_t^{MPS} are latent constructs and are therefore not directly observed. Consequently, the empirical analysis requires a measurement step that links these latent variables to observable data.

The distinction between the structural model and its empirical implementation is important. The systematic component of monetary policy is not directly observed and is approximated empirically by the policy rate implied by the alternative Taylor-type rules, $\hat{i}_t$. The deviation $DMP_t = i_t - \hat{i}_t$ then serves as an empirical proxy for discretionary departures of the realized policy rate from this systematic benchmark. Similarly, the latent monetary policy innovation ϵ_t^{MPS} is approximated by the externally identified high-frequency monetary policy shocks of [Jarocinski and Karadi \(2020\)](#).

Similarly, the theoretical model contains the latent monetary policy innovation ϵ_t^{MPS} , whereas the empirical analysis employs the externally identified high-frequency monetary policy shocks of [Jarocinski and Karadi \(2020\)](#) as an observable proxy for this innovation.

Replacing the latent monetary-policy variables in the structural causal model with their observable empirical counterparts yields the DAGs introduced in the next subsections. These DAGs represent the empirical counterpart of the theoretical model and allow us to derive valid adjustment sets using Pearl’s backdoor criterion.

4.2. Directed Acyclic Graphs and Non-parametric Identification

To identify the causal effects of our monetary policy measures on firm-level TFP, we employ the structural causal model framework of [Pearl \(2009\)](#). The framework represents causal assumptions using DAGs, where nodes denote variables and directed edges represent causal relationships. DAGs provide a transparent representation of the assumed causal structure and identify which variables should be conditioned on to obtain causal effects from observational data.

Three graphical structures are particularly relevant. A *fork* ($X \leftarrow Z \rightarrow Y$) represents confounding because Z is a common cause of X and Y . A *chain* ($X \rightarrow Z \rightarrow Y$) represents a causal transmission channel, so conditioning on Z removes part of the effect of interest. A *collider* ($X \rightarrow Z \leftarrow Y$) is jointly determined by X and Y ; conditioning on it induces spurious dependence through collider bias. Consequently, valid identification requires conditioning on confounders while avoiding mediators and colliders.

Throughout the paper, causal identification is based on the backdoor criterion ([Pearl, 1993, 2009](#)).

Definition 4.1 (Backdoor Criterion). *A set of variables Z satisfies the backdoor criterion relative to an ordered pair (X, Y) if (i) no element of Z is a descendant of X , and (ii) Z blocks every path between X and Y containing an arrow pointing into X . Under these conditions, conditioning on Z removes confounding while preserving the directed causal effect from X to Y .*

Whenever the backdoor criterion holds, the causal effect is identified by the backdoor adjustment formula

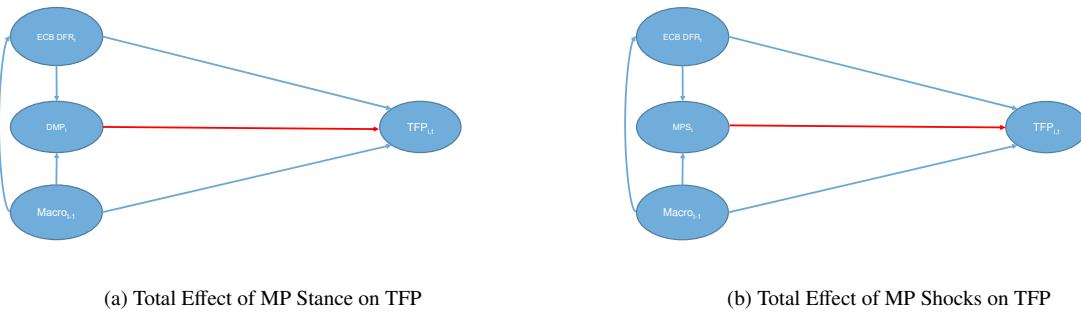
$$P(Y \mid \text{do}(X = x)) = \int_z P(Y \mid X = x, Z = z) P(Z = z) dz. \quad (25)$$

Equation (25) is a direct consequence of Pearl’s do-calculus. Rather than describing the three rules of do-calculus explicitly, we use them to derive the identifying adjustment sets implied by the theoretical model. In the following subsections, we construct the DAGs corresponding to our structural model and identify the adjustment sets required to estimate both the total and the controlled direct effects of monetary policy on firm-level TFP. The DAGs therefore establish non-parametric identification of the causal estimands. The subsequent panel regressions provide parametric estimators of these identified causal effects.

4.3. Identifying the Total Effects of Monetary Policy Stance and Shocks on TFP

We now derive the identifying assumptions implied by the structural causal model. Figure 1 presents the corresponding DAGs for the total effects of monetary policy stance and monetary policy shocks on firm-level TFP. In the empirical implementation, the ECB deposit facility rate (DFR_t) corresponds to the policy rate r_t , while DMP_t and MPS_t denote the empirical proxies for the latent discretionary monetary policy component and monetary policy shocks, respectively. The vector M_{t-1} contains the macroeconomic variables entering the estimated policy rule.

Figure 1: Total Effects of Monetary Policy Stance and Shocks on TFP



These figures show the DAGs corresponding to our causal model. Nodes represent variables or variable groups, and arrows indicate assumed causal relationships. The left panel focuses on monetary policy stance (DMP), while the right panel focuses on monetary policy shocks (MPS).

The DAGs are obtained by replacing the latent monetary-policy variables in the structural causal model with the observable policy measures introduced in Section 4.1. Accordingly,

causal identification is formulated with respect to the empirical variables DFR_t , DMP_t , and MPS_t , while preserving the causal structure implied by the theoretical model.

The identifying assumptions follow directly from the institutional setting. Individual Austrian firms are too small to influence euro-area monetary policy or aggregate macroeconomic conditions. Reverse causality from firm-level productivity to the ECB deposit facility rate, the monetary policy stance, or monetary policy shocks is therefore unlikely. The primary identification challenge instead arises from aggregate shocks, such as inflationary pressures, energy-price shocks, financial disruptions, or aggregate demand fluctuations, that simultaneously affect monetary policy and firm-level productivity. In the DAGs, these common causes generate backdoor paths between monetary policy and TFP. Consequently, the role of the macroeconomic adjustment set is to block these confounding paths and thereby satisfy the backdoor criterion.

The adjustment set implied by the DAG is therefore

$$Z_t = (DFR_t, M_{t-1}),$$

where M_{t-1} contains core inflation, energy prices, GDP growth, and the slope of the yield curve. These variables block the backdoor paths from aggregate macroeconomic conditions to firm-level productivity, while firm fixed effects absorb time-invariant firm heterogeneity. Consequently, identification relies on within-firm variation after conditioning on the common macroeconomic environment. For consistency, we employ the same adjustment set when estimating the effects of high-frequency monetary policy shocks, although these shocks are constructed to be orthogonal to contemporaneous macroeconomic news (Altavilla et al., 2019; Jarocinski and Karadi, 2020).

Under the maintained assumptions, the total causal effect of the monetary policy stance is identified by the backdoor-adjustment formula

$$P(TFP \mid \text{do}(DMP)) = \int_z P(TFP \mid DMP = dmp, Z = z) P(Z = z) dz. \quad (26)$$

Accordingly, identification requires that, conditional on the adjustment set Z_t and the firm fixed effects, no omitted aggregate confounders jointly affect monetary policy and firm-level productivity.

To operationalize this estimand, we impose a linear specification and estimate

$$TFP_{i,t} = \mu_i + \gamma_1 DMP_t + \gamma_2 DFR_t + \theta^\top M_{t-1} + \epsilon_{i,t}. \quad (27)$$

Substituting the definition of discretionary monetary policy, $DMP_t = DFR_t - \widehat{DFR}_t$, into Eq. (27) yields

$$TFP_{i,t} = \mu_i + (\gamma_1 + \gamma_2) DFR_t - \gamma_1 \widehat{DFR}_t + \theta^\top M_{t-1} + \epsilon_{i,t}.$$

Accordingly, the specification decomposes the observed policy rate into a systematic com-

ponent, approximated by the benchmark policy rule, and a discretionary deviation from that benchmark. The coefficient γ_2 captures the effect of the overall level of the policy rate, whereas γ_1 measures the effect of the empirical proxy for discretionary monetary policy, defined as the deviation of the realized ECB deposit facility rate from the benchmark implied by the Taylor rule. Since the systematic component of monetary policy is not directly observable, it is approximated using Eq. (17), Eq. (18), or Eq. (19). Consequently, γ_1 measures the effect of policy actions that are more restrictive or accommodative than implied by macroeconomic fundamentals.

In Eq. (27), firm fixed effects (μ_i) absorb all time-invariant differences across firms, including managerial ability, technology, production efficiency, and persistent financing conditions. Consequently, the empirical specification does not identify whether financially constrained firms operate at permanently lower levels of TFP. Instead, identification relies on within-firm variation over time and estimates the dynamic response of firm-level productivity to changes in monetary policy and financing conditions.

For the total effect of monetary policy shocks, the same adjustment set, $Z_t = (DFR_t, M_{t-1})$, satisfies the backdoor criterion relative to $(MPS_t, TFP_{i,t})$. The corresponding estimand is

$$P(TFP \mid \text{do}(MPS)) = \int_z P(TFP \mid MPS = mps, Z = z) P(Z = z) dz, \quad (28)$$

which we implement using the regression

$$TFP_{i,t} = \mu_i + \gamma_1 MPS_t + \gamma_2 DFR_t + \theta^\top M_{t-1} + \epsilon_{i,t}. \quad (29)$$

Under the stated assumptions, γ_1 identifies the total causal effect of monetary policy shocks on firm-level TFP.

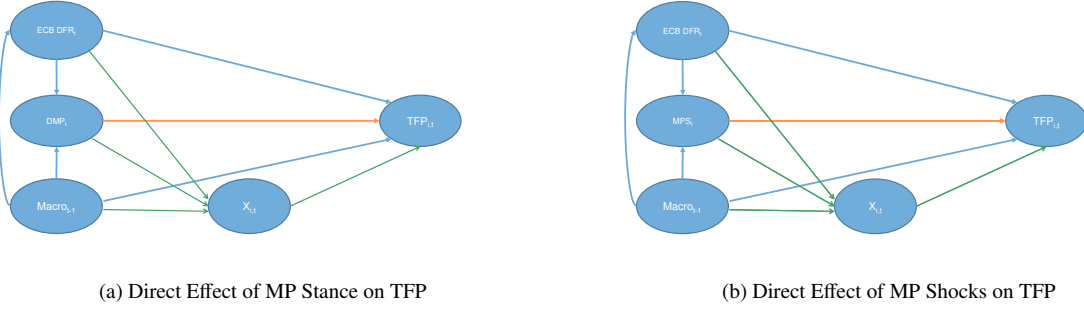
4.4. Identifying the Controlled Direct Effects of Monetary Policy Stance and Shocks on TFP

We now turn to the identification of the *direct* effects of monetary policy stance and monetary policy shocks on firm-level TFP. In contrast to the total effects, the direct effects isolate the impact of monetary policy that does not operate through firm-level adjustments in financial and investment variables.

Motivated by the theoretical model, firms may respond to changes in monetary policy by adjusting retained earnings, leverage, liquidity, debt, external financing dependence, or investment rates. These variables constitute potential mediators through which monetary policy affects productivity. To isolate the direct effect, we therefore condition on a set of firm-level controls $X_{i,t}$ capturing these adjustment channels.

Figure 2 presents the corresponding DAGs, which extend the baseline specification by including the mediator set $X_{i,t}$.

Figure 2: Direct Effects of Monetary Policy Stance and Shocks on TFP



These figures show the DAGs corresponding to the identification of direct effects. Relative to Figure 1, the specification additionally conditions on firm-level mediators $X_{i,t}$.

To identify the direct effect of monetary policy stance, we condition on the mediator set $X_{i,t}$ as well as the baseline adjustment set

$$Z_t = (DFR_t, M_{t-1}).$$

This blocks all backdoor paths between DMP_t and $TFP_{i,t}$ in Figure 2a, including those operating through firm-level responses.

Under the maintained assumptions, the controlled direct effect is identified by

$$P(TFP | \text{do}(DMP = dmp, X = x)) = \int_z P(TFP | DMP = dmp, X = x, Z = z) P(Z = z) dz. \quad (30)$$

We implement this estimand using the linear fixed-effects specification

$$TFP_{i,t} = \mu_i + \gamma_1 DMP_t + \gamma_2 DFR_t + \phi^\top X_{i,t} + \theta^\top M_{t-1} + \epsilon_{i,t}. \quad (31)$$

In this specification, the coefficient γ_1 identifies the direct effect of monetary policy stance on TFP, holding constant firm-level adjustment channels captured by $X_{i,t}$.

For monetary policy shocks, the same conditioning set,

$$Z_t = (DFR_t, M_{t-1}),$$

together with the mediator set $X_{i,t}$, satisfies the backdoor criterion relative to $(MPS_t, TFP_{i,t})$. The corresponding estimand is

$$P(TFP | \text{do}(MPS = mps, X = x)) = \int_z P(TFP | MPS = mps, X = x, Z = z) P(Z = z) dz, \quad (32)$$

which we estimate using

$$TFP_{i,t} = \mu_i + \gamma_1 MPS_t + \gamma_2 DFR_t + \phi^\top X_{i,t} + \theta^\top M_{t-1} + \epsilon_{i,t}. \quad (33)$$

Under the stated assumptions, γ_1 identifies the direct effect of monetary policy shocks on firm-level TFP. Comparing the total and direct effect estimates provides evidence of the importance of indirect transmission channels operating through firm-level financial adjustments.

5. Empirical Results and Extensions

This section presents the empirical evidence on the relationship between monetary policy and firm-level total factor productivity. We proceed in five steps. First, in Section 5.1, we estimate the average effects of the ECB deposit facility rate, discretionary monetary policy (DMP), and high-frequency monetary policy shocks (MPS) on firm-level TFP using the identification strategy developed in Section 4. Second, in Section 5.2, we examine whether these effects differ systematically across firms with different degrees of financial constraints by interacting the monetary policy measures with firm-level financial characteristics. Third, in Sections 5.3 and 5.4, we assess the robustness of the estimated treatment effects to omitted aggregate confounding using the sensitivity analysis of Cinelli and Hazlett (2020). Fourth, we benchmark hypothetical omitted confounders against observed macroeconomic variables to evaluate whether omitted-variable bias of sufficient magnitude is economically plausible. Finally, in Section 5.5, we relate the estimated firm-level productivity effects to aggregate productivity using an Olley-Pakes decomposition (Olley and Pakes, 1996), thereby distinguishing between within-firm productivity improvements and changes in allocative efficiency.

The empirical results yield five main findings. First, tighter monetary policy significantly reduces firm-level total factor productivity. Second, persistent changes in financing conditions, measured by the policy rate and deviations from Taylor-type rules, exert substantially larger effects than high-frequency monetary policy surprises. Third, the transmission of monetary policy is heterogeneous across firms: highly leveraged firms experience significantly larger productivity losses following a monetary tightening, whereas other measures of financial constraints play a considerably smaller role. Fourth, the sensitivity analyses reveal that the estimated effects of the ECB deposit facility rate and discretionary monetary policy are substantially more robust to omitted aggregate confounding than high-frequency monetary policy shocks.⁸ Finally, the Olley–Pakes decomposition shows that improvements in within-firm productivity do not translate one-for-one into aggregate productivity because changes in allocative efficiency partly offset these gains.

5.1. Baseline Results

Our theory predicts that firms primarily respond to persistent changes in financing conditions rather than to transitory monetary policy surprises. We test this prediction by comparing the effects of three conceptually distinct measures of monetary policy: the policy rate, deviations from Taylor-type policy rules, and externally identified high-frequency monetary policy shocks.

⁸This ordering closely mirrors the theoretical predictions developed in Section 2. Persistent changes in financing conditions, represented by the policy rate and discretionary monetary policy stance, generate larger and more robust effects on firm-level productivity than transitory monetary policy surprises. The sensitivity analysis provides additional evidence in favor of the proposed transmission mechanism and complements the DAG-based identification strategy developed in Section 4.2.

In Table 2 and Table 3, we present our estimation results using two distinct measures of monetary policy: (1) DMP: deviations from a Taylor-type rule to capture the monetary policy stance, and (2) MPS: high-frequency monetary policy shocks, as in Jarocinski and Karadi (2020). We measure DMP_t by the Taylor Rule 1993 (Taylor, 1993), by the Taylor Rule 1999 (Taylor, 1999), and by the first difference rule (Orphanides and Williams, 2008, 2002), as described in Section 3.3. Each column in Tables 2 and 3 corresponds to one of the two DAGs described in Section 4, i.e., i) direct effect of monetary policy and the DMP / MPS on TFP, and ii) total effect of monetary policy and the stance/shock on TFP.

Overall, our results indicate that contractionary monetary policy—whether captured by an increase in the policy rate or by a surprise tightening shock—significantly reduces TFP. The effect is most pronounced when considering changes in the policy rate (e.g., the ECB’s DFR). While changes in the monetary policy stance and high-frequency shocks also lower TFP, their estimated effects are smaller in magnitude. This finding supports the view that firms primarily respond to persistent changes in the cost of capital, rather than to transitory surprises.

Our theoretical model predicts that financial constraints amplify the effect of monetary policy on TFP. A decline in the policy rate lowers financing costs for all borrowing firms, but the effect is stronger when the upper borrowing constraint binds, because monetary easing additionally relaxes borrowing capacity and reduces the shadow cost of external finance.

This mechanism provides an important interpretation of our empirical results. The strong and robust effect of the policy rate is consistent with a transmission channel operating through financing constraints (see Table 2). At the same time, the relatively small effects of high-frequency monetary policy shocks suggest that transitory fluctuations in interest rates are insufficient to relax binding constraints in a meaningful way (see Table 3). This result is unsurprising, as high-frequency shocks primarily affect financial markets, including sovereign yields, exchange rates, and equity valuations, while having more limited influence on firms’ long-term investment and financing decisions. Instead, persistent changes in the cost of capital are required to affect firms’ financing conditions and, thereby, productivity.

Importantly, these differences should not be interpreted as mere scale effects across alternative monetary policy measures. The policy rate, the monetary policy stance, and high-frequency shocks capture distinct economic objects. The policy rate reflects the level of financing conditions faced by firms, whereas the stance measures deviations from a benchmark policy rule, and high-frequency shocks capture unexpected innovations around this path. Consistent with the summary statistics reported in Table 1, high-frequency shocks exhibit substantially greater dispersion than the policy rate, indicating that their smaller estimated coefficients are not driven by limited variation. Instead, the results suggest that these variables matter less for firm-level productivity.

In our framework, only the level of the policy rate directly governs the tightness of borrowing constraints. This distinction helps explain why the estimated effects of the policy rate are substantially larger: firms respond primarily to the level of the cost of capital rather than to relative deviations or short-lived surprises that do not materially alter financing conditions.

A key observation is that the coefficients associated with the monetary policy stance are remarkably stable across specifications. This suggests that stance changes are largely exogenous from the perspective of the firm, with limited short-run scope for balance sheet adjustment. In

other words, the direct and total effects are nearly identical, as firms cannot swiftly adapt their financial structure in response to a change in stance.

Importantly, our results confirm the adverse impact of financial frictions on productivity growth. In line with our theoretical model, we find that firms with higher cash holdings experience significantly higher TFP, implying that liquidity buffers can mitigate the constraints imposed by limited access to external finance. Conversely, firms operating with greater external financial dependence exhibit significantly lower TFP, highlighting the amplifying role of the borrowing constraint.

The macroeconomic controls primarily serve to satisfy the backdoor criterion implied by the DAGs in Section 4.2. Consequently, unlike the monetary policy coefficients, their estimated coefficients should not be interpreted as causal effects but rather as conditional associations that help isolate the causal effect of monetary policy on firm-level TFP. Turning to these controls, the results are remarkably stable across specifications. Higher core inflation is consistently associated with lower firm-level total factor productivity, suggesting that inflationary environments coincide with lower productive efficiency through mechanisms such as higher input costs, greater price dispersion, or increased economic uncertainty. By contrast, growth in the synthetic energy price index is positively associated with TFP. Since this variable measures changes in energy prices rather than their level, it likely captures cyclical increases in aggregate demand during economic expansions when both energy demand and firm productivity tend to rise simultaneously.

The insignificant coefficient on GDP growth indicates that, conditional on monetary policy and the remaining macroeconomic controls, aggregate output growth provides little additional explanatory power for firm-level productivity. Although this coefficient is not interpreted causally, the result is consistent with our theoretical framework, which emphasizes financing conditions rather than aggregate demand as the primary transmission channel through which monetary policy affects firm-level productivity. Long-term interest rates are positively associated with TFP in most specifications, consistent with the interpretation that they partly reflect stronger long-run growth expectations rather than solely tighter monetary policy.

The results are robust to alternative measures of TFP. Table B.10 in Appendix B re-estimates the complete set of specifications using the Akerberg-Caves-Frazer productivity estimator (Akerberg et al., 2015). The estimated effects of the ECB deposit facility rate and the discretionary monetary policy measures remain virtually unchanged in both magnitude and statistical significance.

In Appendix C, we further examine the role of macroeconomic controls in the context of high-frequency monetary policy shocks. There we show that omitting such controls can change the estimated effects of these shocks on TFP, even when the shocks are purged of central-bank information effects following Jarocinski and Karadi (2020), highlighting the difficulty of fully isolating exogenous monetary policy innovations from broader macroeconomic information (Miranda-Agrippino and Ricco, 2021).

Table 2: Monetary Policy Effects on TFP I: Sectoral and Fixed Effects Models

	Taylor Rule 1993		Taylor Rule 1999		First Difference Rule	
	DMP Direct Effects I	DMP Total Effects I	DMP Direct Effects II	DMP Total Effects II	DMP Direct Effects III	DMP Total Effects III
ECB DFR	-0.1661*** (0.0266)	-0.1941*** (0.0270)	-0.2037*** (0.0286)	-0.2308*** (0.0291)	-0.1325*** (0.0251)	-0.1612*** (0.0255)
DMP Taylor 1993	-0.0061*** (0.0006)	-0.0060*** (0.0007)				
DMP Taylor 1999			-0.0071*** (0.0008)	-0.0069*** (0.0008)		
DMP First difference rule					-0.0074*** (0.0008)	-0.0072*** (0.0008)
Leverage	0.0001 (0.0003)		0.0001 (0.0003)		0.0001 (0.0003)	
Cash holdings	0.0010*** (0.0003)		0.0010*** (0.0003)		0.0010*** (0.0003)	
Interest expense ratio	0.0049*** (0.0015)		0.0047*** (0.0015)		0.0049*** (0.0015)	
External fin. dependence	-0.0010*** (0.0001)		-0.0010*** (0.0001)		-0.0010*** (0.0001)	
Net investment ratio	0.0003*** (0.0001)		0.0003*** (0.0001)		0.0003*** (0.0001)	
$\Delta(\text{Debt})$ ratio	-0.0002*** (0.0001)		-0.0002*** (0.0001)		-0.0002*** (0.0001)	
Low Default Risk	0.0702*** (0.0057)		0.0702*** (0.0057)		0.0703*** (0.0057)	
HICP core (-1)	-0.0312*** (0.0044)	-0.0341*** (0.0047)	-0.0297*** (0.0044)	-0.0326*** (0.0047)	-0.0288*** (0.0044)	-0.0317*** (0.0046)
Synthetic Energy (-1)	0.0005*** (0.0001)	0.0005*** (0.0001)	0.0005*** (0.0001)	0.0006*** (0.0001)	0.0004*** (0.0001)	0.0004*** (0.0001)
GDP growth (-1)	-0.0002 (0.0009)	0.0001 (0.0010)	-0.0003 (0.0009)	-0.0000 (0.0010)	-0.0006 (0.0009)	-0.0002 (0.0010)
IYC 10 years	0.0158*** (0.0054)	0.0195*** (0.0055)	0.0283*** (0.0061)	0.0317*** (0.0063)	0.0038 (0.0049)	0.0079 (0.0051)
R-squared	0.95	0.94	0.95	0.94	0.95	0.94
Within R-Squared	0.13	0.03	0.13	0.03	0.13	0.03
Number of obs.	21,618	21,618	21,618	21,618	21,618	21,618
Number of groups	4,071	4,071	4,071	4,071	4,071	4,071
Average. Obs. group	5.31	5.31	5.31	5.31	5.31	5.31
Min. Obs. group	3	3	3	3	3	3
Max. Obs. Group	11	11	11	11	11	11

Source: Own calculations. OeNB. ECB SDW. Bloomberg.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. We use cluster robust standard errors with clustering at the firm level. As a robustness check, we also use two-way clustered standard errors at the firm and year level. Results can be found in the Online Appendix.

The dependent variable is the total factor productivity estimated by the fixed effects model in [Ernst and Sigmund \(2023\)](#).

We estimate the models “DMP Direct Effects I” and “DMP Total Effects I” with the deviation from monetary policy rules calculated from the Taylor Rule 1993, which is estimated by Eq. (17).

We estimate the models “DMP Direct Effects II” and “DMP Total Effects II” with the deviation from monetary policy rules calculated from the Taylor Rule 1999, which is estimated by Eq. (18).

We estimate the models “DMP Direct Effects III” and “DMP Total Effects III” with the deviation from monetary policy rules calculated from the first difference rule, which is estimated by Eq. (19).

Leverage ratio, cash holdings, interest rate expense ratio, external financial debt ratio, net investment ratio, $\Delta(\text{Debt})$ ratio) are explained in Section 3.1 and are suggested by the literature to measure financial frictions.

The deviations from monetary policy rules (DMP) either refers to the deviation from [Taylor \(1993\)](#), as defined in Eq. (17), to the deviation from [Taylor \(1999\)](#), as defined in Eq. (18), or to the deviation from the first difference rule, as defined in Eq. (19).

Table 3: High-Frequency Monetary Policy Effects on TFP: Sectoral and Fixed Effects Models

	High-frequency instrument based on Jarocinski and Karadi (2020)			
	Static MPS Direct Effects I	Static MPS Total Effects I	Dynamic MPS Direct Effects II	Dynamic MPS Total Effects II
ECB DFR	−0.0713*** (0.0239)	−0.1021*** (0.0243)	−0.1698*** (0.0281)	−0.1965*** (0.0284)
MPS High-Freq.	−0.0005* (0.0002)	−0.0005* (0.0003)	−0.0017*** (0.0002)	−0.0016*** (0.0002)
Leverage	0.0000 (0.0003)		0.0001 (0.0003)	
Cash holdings	0.0010*** (0.0003)		0.0010*** (0.0003)	
Interest expense ratio	0.0036** (0.0015)		0.0044*** (0.0015)	
External fin. dependence	−0.0010*** (0.0001)		−0.0010*** (0.0001)	
Net investment ratio	0.0003*** (0.0001)		0.0003*** (0.0001)	
Δ(Debt) ratio	−0.0002*** (0.0001)		−0.0002*** (0.0001)	
Low Default Risk	0.0699*** (0.0057)		0.0702*** (0.0057)	
HICP core (-1)	−0.0261*** (0.0046)	−0.0291*** (0.0048)	−0.0417*** (0.0049)	−0.0442*** (0.0051)
Synthetic Energy (-1)	0.0004*** (0.0001)	0.0005*** (0.0001)	0.0005*** (0.0001)	0.0006*** (0.0001)
GDP growth (-1)	−0.0005 (0.0011)	−0.0002 (0.0011)	0.0039*** (0.0010)	0.0040*** (0.0011)
IYC 10 years	−0.0077 (0.0048)	−0.0036 (0.0049)	0.0227*** (0.0064)	0.0257*** (0.0065)
R-squared	0.95	0.94	0.95	0.94
Within R-Squared	0.13	0.03	0.13	0.03
Number of obs.	21,618	21,618	21,618	21,618
Number of groups	4,071	4,071	4,071	4,071
Average. Obs. group	5.31	5.3102	5.31	5.31
Min. Obs. group	3	3	3	3
Max. Obs. Group	11	11	11	11

Source: Own calculations. OeNB. ECB SDW. Bloomberg.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. We use cluster robust standard errors with clustering at the firm level. As a robustness check, we also use two-way clustered standard errors at the firm and year level. Results can be found in the Online Appendix.

The dependent variable is the total factor productivity estimated by the fixed effects model in [Ernst and Sigmund \(2023\)](#).

Leverage ratio, cash holdings, interest rate expense ratio, external financial debt ratio, net investment ratio, Δ(Debt ratio) are explained in Section 3.1 and are suggested by the literature to measure financial frictions.

The static shock refers to a weighted average of the high-frequency instrument of [Jarocinski and Karadi \(2020\)](#) as suggested by [Albrizio et al. \(2023\)](#). The dynamic monetary shock refers to the cumulative sum of the high-frequency instrument determined in a 12-month rolling window.

Although the policy rate, discretionary monetary policy measures, and high-frequency monetary policy shocks are all interest-rate-based measures, they differ in their construction, empirical distributions, and degree of variation. Their estimated coefficients are therefore not directly comparable. To facilitate an economically meaningful comparison, Table 4 reports the implied change in firm-level TFP associated with an interquartile-range (IQR) change in each monetary policy measure. The calculation combines the estimated total-effect coefficients from Tables 2 and 3 with the corresponding IQR of each monetary policy variable. The results show that an IQR change in the ECB deposit facility rate is associated with by far the largest change in firm-level TFP, while the implied effects of discretionary monetary policy and high-frequency monetary policy shocks are considerably smaller. This pattern is consistent with our broader

finding that firm productivity responds more strongly to persistent changes in financing conditions than to short-lived policy surprises.

Table 4: Economic Significance of Alternative Monetary Policy Measures

	Q1	Q3	IQR	Coefficient	Implied ΔTFP
ECB Deposit Facility Rate	-0.21	0.47	0.68	-0.1941	-0.1320
DMP (Taylor Rule 1993)	-3.16	-1.33	1.83	-0.0060	-0.0110
DMP (Taylor Rule 1999)	-3.36	-0.96	2.40	-0.0069	-0.0166
DMP (First Difference Rule)	-0.89	1.85	2.74	-0.0072	-0.0197
Static High-Frequency MPS	-1.67	7.94	9.61	-0.0004	-0.0038
Dynamic High-Frequency MPS	-0.46	5.57	6.03	-0.0016	-0.0096

Source: Own calculations.

The table reports economically comparable effects of the alternative monetary policy measures. Since the monetary policy variables differ in their construction, units of measurement, and empirical distributions, their regression coefficients are not directly comparable.

The interquartile range (IQR) is computed as $IQR = Q_3 - Q_1$, where Q_1 and Q_3 denote the first and third quartiles reported in Table 1.

The column "Coefficient" reports the estimated total-effect coefficients from Tables 2 and 3. The column "Implied ΔTFP " reports the change in firm-level total factor productivity associated with an interquartile-range change in the respective monetary policy measure, computed as $\Delta TFP = \hat{\beta} \times IQR$.

Comparing economically meaningful changes rather than raw regression coefficients shows that an IQR change in the ECB deposit facility rate is associated with the largest change in firm-level TFP. The implied effects of discretionary monetary policy are smaller, while high-frequency monetary policy shocks exhibit the smallest economic effects.

5.2. Heterogeneous Effects

The baseline estimates in Section 5.1 identify the average effect of monetary policy on firm productivity. Our theoretical model, however, predicts that this effect should depend on firms' financial conditions. Firms facing tighter financing constraints are expected to experience a larger decline in productivity when monetary policy tightens because external finance becomes more expensive and investment opportunities are more likely to be foregone. To test this prediction, we interact the monetary policy indicators with several firm-specific measures of financial constraints, namely leverage, cash holdings, external finance dependence, and the interest expense ratio.

To facilitate the interpretation of the interaction effects, all firm-specific financial variables entering the interaction terms are expressed as deviations from each firm's historical average.⁹ Since the financial variables are measured in different units, the interaction coefficients should not be compared directly. Instead, we evaluate the implied marginal effects for economically meaningful within-firm changes.

Table 5 reports the estimation results. Across all monetary policy specifications, tighter monetary policy significantly reduces firm-level productivity. The estimated coefficients are remarkably stable across the different Taylor-rule measures and high-frequency monetary policy shocks, indicating that the average contractionary effect of monetary policy on productivity is robust to alternative measures of the policy stance.

⁹In a standard interaction model, the coefficient on the monetary policy variable measures its effect when the interacting variable equals zero. For example, if $TFP_{i,t} = \beta_1 MP_t + \beta_2 Lev_{i,t} + \beta_3 (MP_t \times Lev_{i,t}) + X'_{i,t} \gamma + \epsilon_{i,t}$, then the marginal effect of monetary policy is $\frac{\partial TFP_{i,t}}{\partial MP_t} = \beta_1 + \beta_3 Lev_{i,t}$. Since virtually all firms in our sample hold at least some debt, the case $Lev_{i,t} = 0$ is economically uninformative. We therefore express each financial characteristic as a deviation from its firm-specific historical average before constructing the interaction terms. Consequently, the coefficient on the monetary policy variable measures its effect for a firm whose financial position is at its own long-run average, while the interaction coefficients describe how this effect changes when a firm's financial position improves or deteriorates relative to its historical norm.

Among the interaction terms, leverage is the only financial characteristic that consistently amplifies the transmission of monetary policy. The interaction between the ECB deposit facility rate and leverage is negative and statistically significant across all specifications. Hence, firms whose leverage exceeds their own historical average experience a significantly larger decline in productivity following a monetary tightening. This finding is fully consistent with the theoretical model, in which highly leveraged firms face stronger financing frictions and higher marginal borrowing costs when external financing conditions deteriorate.

By contrast, we find no robust evidence that the productivity effects of monetary policy systematically depend on firms' cash holdings or their interest expense ratio. Although these variables are economically relevant indicators of firms' financing conditions, their interaction with monetary policy is generally statistically insignificant.

External finance dependence exhibits a different pattern. The level effect is consistently negative, indicating that firms with greater reliance on external finance display lower productivity on average. However, the interaction with monetary policy is comparatively weak and only marginally significant in some specifications. Consequently, the data provide little evidence that short-run fluctuations in firms' external financing needs materially strengthen the transmission of monetary policy once leverage is taken into account.

Table 5: Heterogeneous Productivity Effects of Monetary Policy

	Taylor Rule 1993	Taylor Rule 1999	First Difference Rule	Static MPS	Dynamic MPS
ECB DFR	-0.1816*** (0.0268)	-0.2186*** (0.0288)	-0.1489*** (0.0254)	-0.1049*** (0.0248)	-0.1890*** (0.0282)
DMP Taylor 1993	-0.0060*** (0.0007)				
DMP Taylor 1999		-0.0069*** (0.0008)			
DMP First difference rule			-0.0073*** (0.0009)		
MPS High-Freq.				-0.0004 (0.0002)	-0.0016*** (0.0002)
ECB DFR x Leverage (within) (-1)	-0.0019*** (0.0007)	-0.0019*** (0.0007)	-0.0019*** (0.0007)	-0.0019*** (0.0007)	-0.0019*** (0.0007)
ECB DFR x Cash Holdings (within) (-1)	-0.0003 (0.0009)	-0.0003 (0.0009)	-0.0003 (0.0009)	-0.0003 (0.0009)	-0.0003 (0.0009)
ECB DFR x Ext. fin. Dep. (within) (-1)	0.0004* (0.0003)	0.0004* (0.0003)	0.0004* (0.0003)	0.0005* (0.0003)	0.0004* (0.0003)
ECB DFR x Int. exp ratio (within) (-1)	-0.0005 (0.0041)	-0.0011 (0.0041)	-0.0005 (0.0041)	-0.0091** (0.0040)	-0.0040 (0.0040)
Leverage	0.0003 (0.0003)	0.0003 (0.0003)	0.0003 (0.0003)	0.0002 (0.0003)	0.0003 (0.0003)
Cash holdings	0.0009*** (0.0003)	0.0009*** (0.0003)	0.0008*** (0.0003)	0.0008** (0.0003)	0.0008** (0.0003)
Interest expense ratio	0.0049*** (0.0015)	0.0047*** (0.0015)	0.0049*** (0.0015)	0.0040*** (0.0015)	0.0045*** (0.0015)
External fin. dependence	-0.0010*** (0.0001)	-0.0010*** (0.0001)	-0.0010*** (0.0001)	-0.0010*** (0.0001)	-0.0010*** (0.0001)
Net investment ratio	0.0003*** (0.0001)	0.0003*** (0.0001)	0.0003*** (0.0001)	0.0003*** (0.0001)	0.0003*** (0.0001)
$\Delta(\text{Debt})$ ratio	-0.0002*** (0.0001)	-0.0002*** (0.0001)	-0.0002*** (0.0001)	-0.0002*** (0.0001)	-0.0002*** (0.0001)
Low Default Risk	0.0694*** (0.0057)	0.0694*** (0.0057)	0.0695*** (0.0057)	0.0692*** (0.0057)	0.0695*** (0.0057)
HICP core (-1)	-0.0328*** (0.0047)	-0.0314*** (0.0047)	-0.0304*** (0.0047)	-0.0303*** (0.0050)	-0.0435*** (0.0051)
Synthetic Energy (-1)	0.0005*** (0.0001)	0.0006*** (0.0001)	0.0005*** (0.0001)	0.0005*** (0.0001)	0.0006*** (0.0001)
GDP growth (-1)	-0.0007 (0.0009)	-0.0008 (0.0009)	-0.0011 (0.0009)	-0.0010 (0.0010)	0.0033*** (0.0010)
IYC 10 years	0.0186*** (0.0056)	0.0310*** (0.0063)	0.0070 (0.0052)	0.0000 (0.0051)	0.0264*** (0.0065)
R-squared	0.95	0.95	0.95	0.95	0.95
Within R-Squared	0.14	0.14	0.14	0.14	0.14
Number of obs.	20,875	20,875	20,875	20,875	20,875
Number of groups	3,915	3,915	3,915	3,915	3,915
Average. Obs. group	5.33	5.33	5.33	5.33	5.33
Min. Obs. group	3	3	3	3	3
Max. Obs. Group	11	11	11	11	11

Source: Own calculations. OeNB. ECB SDW. Bloomberg.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. We use cluster robust standard errors with clustering at the firm level. As a robustness check, we also use two-way clustered standard errors at the firm and year level. Results can be found in the Online Appendix.

The dependent variable is firm-level total factor productivity (TFP) estimated using the fixed-effects production function estimator described in Section 3.1. All specifications are estimated using firm fixed effects. Standard errors clustered at the firm level are reported in parentheses. The interaction terms are constructed by interacting the ECB deposit facility rate with the corresponding firm-specific financial characteristic expressed as a deviation from its firm-specific historical average. Consequently, the coefficient on the ECB deposit facility rate measures the effect of monetary policy for a firm whose financial characteristics are at their own historical averages, while the interaction coefficients capture how this effect changes as firms become more or less financially constrained relative to their own long-run average. All regressions additionally include the macroeconomic control variables reported in the table. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

5.3. Sensitivity Analysis: Policy Rate

The causal identification strategy developed in Section 4.2 assumes that, conditional on the adjustment set implied by the DAG, no omitted aggregate variable simultaneously affects euro-area monetary policy and firm-level productivity. While the DAG motivates the required adjustment set, this identifying assumption cannot be tested directly. We therefore assess the sensitivity of the estimated policy-rate effects to potential omitted aggregate confounding.

The remaining identification threat is not omitted firm characteristics, which are absorbed by firm fixed effects, but omitted aggregate shocks that simultaneously influence monetary policy and firm productivity. To quantify the potential importance of such confounding, we employ the sensitivity analysis proposed by Cinelli and Hazlett (2020). Rather than asking whether omitted-variable bias exists, the approach measures how strongly an omitted confounder would

have to be related to both the treatment and the outcome to explain away the estimated policy-rate effect or render it statistically insignificant.

Table 6 reports the corresponding robustness values. Across the three Taylor-rule specifications, the robustness values range between approximately 0.06 and 0.07. Hence, an omitted aggregate confounder would have to explain roughly six to seven percent of the residual variation in both the ECB deposit facility rate and firm-level productivity, conditional on the observed controls, in order to eliminate the estimated effect. The corresponding robustness values for the high-frequency monetary policy specifications are smaller, indicating that unexpected policy surprises are more sensitive to omitted confounding than persistent policy-rate movements.

While the robustness values provide quantitative thresholds, they do not indicate whether confounders of this magnitude are economically plausible. Following Cinelli and Hazlett (2020), Table 7 therefore benchmarks hypothetical omitted confounders against observed macroeconomic variables. Specifically, we calibrate the strength of the omitted confounder to lagged core inflation, lagged synthetic energy prices, and lagged GDP growth.

The benchmark analysis reveals a clear ordering in the importance of these macroeconomic variables. Benchmarking the omitted confounder against GDP growth has virtually no effect on the estimated policy-rate coefficients. This result reflects the weak association between GDP growth and the ECB deposit facility rate once the remaining macroeconomic controls are taken into account. Benchmarking against synthetic energy prices attenuates the estimated policy-rate effects, but the coefficients remain economically large and statistically significant across all specifications. By contrast, calibrating the omitted confounder to core inflation substantially reduces the estimated policy-rate effect and renders it statistically insignificant in several specifications.

This finding is economically intuitive rather than problematic. Core inflation is one of the primary determinants of ECB interest-rate decisions and therefore exhibits a much stronger relationship with the policy rate than the other benchmark variables. Consequently, an omitted confounder with explanatory power comparable to core inflation represents an omitted variable that is intrinsically linked to the ECB's systematic policy reaction function. In contrast, omitted macroeconomic variables with explanatory power comparable to GDP growth or energy prices are insufficient to overturn the estimated policy-rate effects.

Overall, the sensitivity analysis complements the DAG-based identification strategy and supports a causal interpretation of the results. It shows that the estimated effects of the ECB deposit facility rate are robust to plausible omitted macroeconomic confounders and become sensitive mainly to variables that directly enter the ECB's policy rule. This also motivates the use of discretionary monetary policy measures based on deviations from Taylor rules, which remove the systematic response to macroeconomic fundamentals and are therefore less susceptible to omitted-variable bias arising from endogenous policy reactions.

Table 6: Deposit Facility Rate on TFP: Sensitivity Analysis to Unobserved Confounding

	Coefficient	<i>t</i> -value	Partial R^2	RV	RV (5%)
TFP Total Taylor Rule 1993	-0.1942	-9.3468	0.0050	0.0682	0.0543
TFP Total Taylor Rule 1999	-0.2309	-9.9145	0.0056	0.0722	0.0583
TFP Total First Difference Rule	-0.1613	-8.2648	0.0039	0.0605	0.0465
TFP Total Karadi Static MPS	-0.1023	-5.4975	0.0017	0.0407	0.0264
TFP Total Karadi Dynamic MPS	-0.1967	-8.6907	0.0043	0.0635	0.0496

Source: Own calculations.

The table reports the sensitivity analysis of Cinelli and Hazlett (2020) for the main monetary policy specifications.

The “treatment variable” is the ECB deposit facility rate.

Partial R^2 measures the share of the residual variation in firm-level total factor productivity explained by the treatment after controlling for the observed covariates.

RV (Robustness Value) denotes the minimum strength that an omitted confounder must have, in terms of its partial R^2 with both the treatment and the outcome, to reduce the estimated treatment effect to zero.

RV (5%) reports the corresponding robustness value required to render the estimated treatment effect statistically insignificant at the 5% significance level.

Table 7: Deposit Facility Rate on TFP: Sensitivity Analysis Using Benchmark Covariates

Outcome: Model	Treatment	Benchmark	$R^2_{D,Z}$	$R^2_{Y,Z}$	Adj. Coef.	Adj. S.E.	Adj. <i>t</i>	Lower 95%	Upper 95%
TFP: Taylor Rule 1993	ECB DFR	1x HICP core (-1)	0.3156	0.0084	-0.0232	0.0250	-0.928	-0.0722	0.0258
TFP: Taylor Rule 1993	ECB DFR	1x Synthetic Energy (-1)	0.1148	0.0037	-0.1343	0.0220	-6.093	-0.1775	-0.0911
TFP: Taylor Rule 1993	ECB DFR	1x GDP growth (-1)	0.0010	0.0000	-0.1941	0.0208	-9.337	-0.2349	-0.1534
TFP: Taylor Rule 1999	ECB DFR	1x HICP core (-1)	0.2228	0.0063	-0.0999	0.0263	-3.794	-0.1516	-0.0483
TFP: Taylor Rule 1999	ECB DFR	1x Synthetic Energy (-1)	0.1330	0.0047	-0.1483	0.0250	-5.943	-0.1973	-0.0994
TFP: Taylor Rule 1999	ECB DFR	1x GDP growth (-1)	0.0019	0.0000	-0.2309	0.0233	-9.903	-0.2766	-0.1852
TFP: FD Rule	ECB DFR	1x HICP core (-1)	0.3195	0.0074	-0.0094	0.0236	-0.400	-0.0556	0.0368
TFP: FD Rule	ECB DFR	1x Synthetic Energy (-1)	0.1049	0.0027	-0.1152	0.0206	-5.593	-0.1556	-0.0748
TFP: FD Rule	ECB DFR	1x GDP growth (-1)	0.0000	0.0000	-0.1612	0.0195	-8.263	-0.1995	-0.1230
TFP: Karadi Static MPS	ECB DFR	1x HICP core (-1)	0.3508	0.0057	0.0342	0.0230	1.485	-0.0109	0.0793
TFP: Karadi Static MPS	ECB DFR	1x Synthetic Energy (-1)	0.1500	0.0028	-0.0475	0.0202	-2.359	-0.0871	-0.0080
TFP: Karadi Static MPS	ECB DFR	1x GDP growth (-1)	0.0019	0.0000	-0.1022	0.0186	-5.487	-0.1387	-0.0657
TFP: Karadi Dynamic MPS	ECB DFR	1x HICP core (-1)	0.6336	0.0272	0.4526	0.0369	12.274	0.3803	0.5249
TFP: Karadi Dynamic MPS	ECB DFR	1x Synthetic Energy (-1)	0.1503	0.0048	-0.1094	0.0245	-4.466	-0.1574	-0.0614
TFP: Karadi Dynamic MPS	ECB DFR	1x GDP growth (-1)	0.1050	0.0008	-0.1686	0.0239	-7.048	-0.2154	-0.1217

Source: Own calculations.

The table reports the benchmark analysis from the sensitivity framework of Cinelli and Hazlett (2020). The treatment variable is the ECB deposit facility rate (ECB DFR).

For each specification, the omitted confounder is assumed to be as predictive as one of the observed benchmark covariates. The table reports the resulting adjusted treatment effect after accounting for an omitted confounder with the same explanatory power as the benchmark variable.

$R^2_{D,Z}$ denotes the partial R^2 of the hypothetical omitted confounder with the treatment (ECB DFR), while $R^2_{Y,Z}$ denotes its partial R^2 with firm-level TFP conditional on the observed controls.

Adj. Coef., Adj. S.E., Adj. *t*, and the confidence interval report the treatment effect after adjusting for omitted-variable bias under the assumed benchmark strength.

5.4. Sensitivity Analysis: DMP and MPS

The previous subsection demonstrated that the estimated effects of the ECB deposit facility rate are robust to omitted aggregate confounding. An important question is whether this robustness also extends to the discretionary monetary policy (DMP) measures derived from deviations from Taylor rules and to high-frequency monetary policy shocks. Since the former remove the systematic response of monetary policy to macroeconomic fundamentals by construction, one would expect them to be even less susceptible to omitted aggregate variables such as inflation or output growth.

Table 8 reports the sensitivity statistics for the DMP and MPS specifications. Across all three Taylor-rule measures, the robustness values range from 0.064 to 0.068, while the corresponding

robustness values required to render the estimated coefficients statistically insignificant remain between 0.050 and 0.054. Thus, an omitted confounder would have to explain roughly six to seven percent of the residual variation in both discretionary monetary policy and firm-level productivity to eliminate the estimated causal effect. These values are very similar to, and in some cases slightly larger than, those obtained for the ECB deposit facility rate.

By contrast, the high-frequency monetary policy shocks exhibit considerably weaker robustness. The static measure has a robustness value of only 0.010, implying that even relatively weak omitted confounding could eliminate the estimated effect. Although the dynamic specification is substantially more robust, with a robustness value of 0.053, it nevertheless remains below the Taylor-rule measures. Overall, the robustness values suggest that discretionary monetary policy is considerably less sensitive to omitted-variable bias than high-frequency monetary policy surprises.

While the robustness values quantify the strength of confounding required to overturn the results, they do not indicate whether confounders of such magnitude are economically plausible. We therefore benchmark hypothetical omitted confounders against the observed macroeconomic variables that constitute the principal remaining identification concern, namely lagged core inflation, lagged synthetic energy prices, and lagged GDP growth.

Table 9 reveals a clear contrast between discretionary monetary policy measures and high-frequency monetary policy shocks. Across all three Taylor-rule specifications, calibrating the omitted confounder to core inflation, synthetic energy prices, or GDP growth produces only negligible changes in the estimated DMP coefficients, which remain economically stable and highly statistically significant. This robustness is consistent with the construction of the DMP measures, as Taylor-rule deviations remove the systematic policy component explained by macroeconomic fundamentals, leaving limited scope for additional confounding from inflation or aggregate activity. By contrast, the high-frequency shock estimates are considerably more sensitive. Benchmarking against core inflation eliminates the significance of both the static and dynamic measures, while GDP growth substantially attenuates their effects. Only the dynamic shock remains significant when the confounder is calibrated to synthetic energy prices. Overall, the results support the identifying strategy behind the DMP measures and indicate that they are substantially less vulnerable to omitted aggregate confounding than high-frequency monetary policy surprises.

Taken together, the two sensitivity analyzes provide complementary evidence supporting the causal interpretation of the main results. Whereas the previous subsection demonstrates that the estimated effects of the ECB policy rate are robust to economically plausible omitted aggregate shocks, the present analysis shows that removing the systematic macroeconomic component of monetary policy through Taylor-rule deviations yields an even more robust measure of discretionary monetary policy. This pattern is fully consistent with the theoretical framework developed in Section 2, which predicts that persistent changes in financing conditions have substantially larger and more durable effects on firms' productivity than transitory announcement surprises.

Table 8: DMP and MPS on TFP: Sensitivity Analysis to Unobserved Confounding

Outcome: Model	Coefficient	<i>t</i> -value	Partial R^2	RV	RV (5%)
TFP Total Taylor Rule 1993	-0.0060	-9.4513	0.0051	0.0689	0.0550
TFP Total Taylor Rule 1999	-0.0069	-8.9177	0.0045	0.0651	0.0512
TFP Total First Difference Rule	-0.0072	-9.1258	0.0047	0.0666	0.0527
TFP Total Karadi Static MPS	-0.0005	-1.6823	0.0002	0.0126	0.0000
TFP Total Karadi Dynamic MPS	-0.0016	-7.0654	0.0028	0.0520	0.0378

Source: Own calculations.

The table reports the sensitivity analysis of Cinelli and Hazlett (2020) for the main monetary policy specifications.

The “treatment variable” is the DMP and the MPS.

Partial R^2 measures the share of the residual variation in firm-level total factor productivity explained by the treatment after controlling for the observed covariates.

RV (Robustness Value) denotes the minimum strength that an omitted confounder must have, in terms of its partial R^2 with both the treatment and the outcome, to reduce the estimated treatment effect to zero.

RV (5%) reports the corresponding robustness value required to render the estimated treatment effect statistically insignificant at the 5% significance level.

Table 9: DMP and MPS on TFP: Sensitivity Analysis Using Benchmark Covariates

Outcome: Model	Treatment	Benchmark	$R^2_{D,Z}$	$R^2_{Y,Z}$	Adj. Coef.	Adj. S.E.	Adj. <i>t</i>	Lower 95%	Upper 95%
TFP: Taylor Rule 1993	DMP Taylor 1993	1x HICP core (-1)	0.0039	0.0044	-0.0056	0.0006	-8.901	-0.0069	-0.0044
TFP: Taylor Rule 1993	DMP Taylor 1993	1x Synthetic Energy (-1)	0.0001	0.0029	-0.0059	0.0006	-9.413	-0.0072	-0.0047
TFP: Taylor Rule 1993	DMP Taylor 1993	1x GDP growth (-1)	0.0099	0.0000	-0.0060	0.0006	-9.389	-0.0072	-0.0047
TFP: Taylor Rule 1999	DMP Taylor 1999	1x HICP core (-1)	0.0006	0.0040	-0.0068	0.0008	-8.732	-0.0083	-0.0053
TFP: Taylor Rule 1999	DMP Taylor 1999	1x Synthetic Energy (-1)	0.0101	0.0037	-0.0063	0.0008	-8.084	-0.0078	-0.0048
TFP: Taylor Rule 1999	DMP Taylor 1999	1x GDP growth (-1)	0.0087	0.0000	-0.0069	0.0008	-8.874	-0.0085	-0.0054
TFP: First Difference Rule	DMP FD rule	1x HICP core (-1)	0.0000	0.0038	-0.0072	0.0008	-9.136	-0.0087	-0.0056
TFP: First Difference Rule	DMP FD rule	1x Synthetic Energy (-1)	0.0083	0.0022	-0.0067	0.0008	-8.527	-0.0083	-0.0052
TFP: First Difference Rule	DMP FD rule	1x GDP growth (-1)	0.0044	0.0000	-0.0072	0.0008	-9.093	-0.0087	-0.0056
TFP: Static MPS	MPS High-Freq.	1x HICP core (-1)	0.1644	0.0038	0.0005	0.0003	1.776	-0.0001	0.0011
TFP: Static MPS	MPS High-Freq.	1x Synthetic Energy (-1)	0.1381	0.0027	0.0003	0.0003	1.011	-0.0003	0.0009
TFP: Static MPS	MPS High-Freq.	1x GDP growth (-1)	0.1544	0.0000	-0.0005	0.0003	-1.492	-0.0011	0.0001
TFP: Dynamic MPS	MPS High-Freq.	1x HICP core (-1)	0.2010	0.0092	-0.0002	0.0003	-0.637	-0.0007	0.0003
TFP: Dynamic MPS	MPS High-Freq.	1x Synthetic Energy (-1)	0.0159	0.0037	-0.0014	0.0002	-6.011	-0.0018	-0.0009
TFP: Dynamic MPS	MPS High-Freq.	1x GDP growth (-1)	0.4454	0.0016	-0.0005	0.0003	-1.746	-0.0011	0.0001

Source: Own calculations.

The table reports the benchmark analysis from the sensitivity framework of Cinelli and Hazlett (2020). The treatment variable is either the discretionary monetary policy measure (DMP) or the static or dynamic high-frequency monetary policy shock (MPS) (Jarocinski and Karadi, 2020), depending on the specification.

For each specification, the omitted confounder is assumed to be as predictive as one of the observed benchmark covariates. The table reports the resulting adjusted treatment effect after accounting for an omitted confounder with the same explanatory power as the benchmark variable.

$R^2_{D,Z}$ denotes the partial R^2 of the hypothetical omitted confounder with the treatment (ECB DFR), while $R^2_{Y,Z}$ denotes its partial R^2 with firm-level TFP conditional on the observed controls.

Adj. Coef., Adj. S.E., Adj. *t*, and the confidence interval report the treatment effect after adjusting for omitted-variable bias under the assumed benchmark strength.

5.5. Aggregate Productivity Implications

Thus far, the analysis has established that monetary policy causally affects firm-level total factor productivity through firms’ financing conditions. An important question is whether these firm-level productivity effects translate into changes in aggregate productivity. Aggregate productivity may change for two conceptually distinct reasons. First, firms may become more productive individually because they invest in productivity-enhancing technologies. Second, aggregate productivity may change because market shares are reallocated toward more productive firms. The first mechanism corresponds to improvements in within-firm productivity, whereas the second reflects changes in allocative efficiency. Distinguishing between these channels is important because monetary policy may influence both.

Following [Olley and Pakes \(1996\)](#), aggregate productivity can be decomposed into the average productivity of firms and an allocative efficiency component:

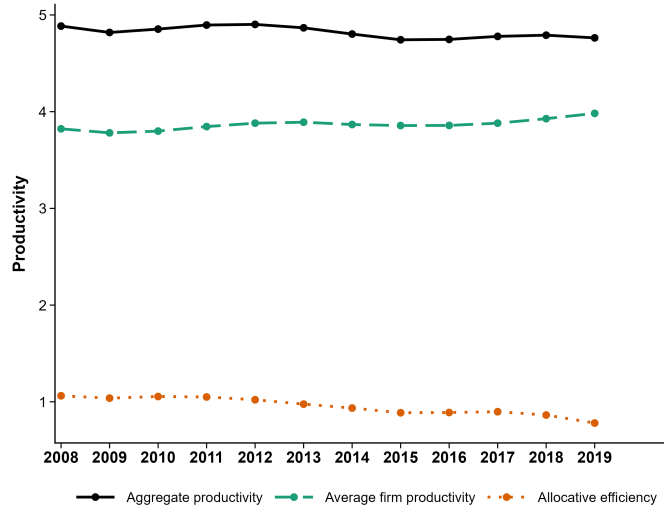
$$P_t = \bar{p}_t + \sum_i (s_{it} - \bar{s}_t)(p_{it} - \bar{p}_t), \quad (34)$$

where p_{it} denotes firm-level productivity and s_{it} denotes the firm's revenue share. The first term captures improvements in firms' own productivity, whereas the second term measures the extent to which economic activity is concentrated in more productive firms. A larger covariance term indicates a more efficient allocation of resources across firms.

Figure 3 reports the decomposition for the Austrian firm sample. Three patterns emerge. First, average firm-level productivity increases almost continuously over the sample period. Second, aggregate productivity remains comparatively stable. Third, the allocative efficiency component declines steadily, implying that the increase in firms' productivity is partly offset by a weaker allocation of economic activity toward the most productive firms.

Taken together, these patterns suggest that the evolution of aggregate productivity masks two opposing developments. Average productivity within firms improved steadily throughout the sample period, whereas the allocation of economic activity became progressively less efficient. As a consequence, the increase in firms' own productivity translated only partially into higher aggregate productivity.

Figure 3: Olley-Pakes Decomposition of Aggregate Productivity



Notes: The figure reports the Olley-Pakes decomposition ([Olley and Pakes, 1996](#)). Aggregate productivity is decomposed into the average firm-level total factor productivity and an allocative efficiency component, measured as the covariance between firms' revenue shares and their total factor productivity. The average firm-level productivity is calculated from the fixed-effects estimator as in [Ernst and Sigmund \(2023\)](#). Firm revenue shares are computed as each firm's share of total revenue in a given year. Aggregate productivity equals the sum of average firm productivity and the allocative efficiency component. A larger covariance indicates that economic activity is more strongly concentrated among highly productive firms. Average firm productivity increases over the sample period, whereas the allocative efficiency component declines, leaving aggregate productivity broadly stable.

These findings complement the theoretical framework developed in Section 2. The model

predicts that lower financing costs stimulate investment in productivity-enhancing technologies, thereby increasing firms' productivity. The upward trend in average firm-level productivity is consistent with the financing channel proposed by the theoretical model and with the causal firm-level estimates reported in the previous subsection. At the same time, the decomposition illustrates that aggregate productivity depends not only on within-firm improvements but also on allocative efficiency, that is, whether more productive firms account for a larger share of economic activity.

Although the decomposition is descriptive and does not establish a causal relationship between monetary policy and allocative efficiency, it highlights an important implication of the firm-level results. The estimates presented above identify the effect of monetary policy on productivity within firms. Aggregate productivity, however, also depends on the allocation of economic activity across firms. Consequently, improvements in firm-level productivity need not translate one-for-one into higher aggregate productivity if accommodative financing conditions simultaneously weaken the reallocation of resources toward the most productive firms. The decomposition, therefore, suggests that monetary policy may operate through two distinct channels: a within-firm productivity channel, which is causally identified in this paper, and a reallocation channel, which remains descriptive and provides an important direction for future research.

6. Conclusion

This paper develops a theoretical and empirical framework to study how monetary policy affects firm-level total factor productivity in the presence of financial frictions. Extending the models of [Jones \(2003\)](#) and [Levine and Warusawitharana \(2021\)](#), we introduce monetary policy into a dynamic optimization model in which firms allocate scarce financial resources between physical capital and productivity-enhancing investment. The model predicts that monetary policy affects productivity primarily through financing conditions and that these effects become stronger when firms face binding borrowing constraints.

Guided by this theoretical framework, we derive causal identification strategies using DAGs and Pearl's do-calculus and estimate the total and direct effects of monetary policy on firm-level TFP. Using a comprehensive panel of Austrian non-financial firms, we find robust evidence that contractionary monetary policy lowers firm productivity. This result holds whether monetary policy is measured by the policy rate, deviations from rule-based policy, or high-frequency monetary policy shocks.

A key contribution is the distinction between persistent discretionary policy and transitory policy surprises. While both affect productivity in the expected direction, the effects of deviations from monetary policy rules are larger and more robust than those of high-frequency shocks. This finding supports the view that firms adjust productivity-enhancing investment primarily in response to persistent changes in financing conditions rather than short-lived surprises.

Consistent with the theoretical model, financial frictions are an important transmission mechanism. Highly leveraged firms experience significantly larger productivity losses following monetary tightening, suggesting that balance-sheet leverage is a key channel through which monetary policy affects productivity-enhancing investment.

The Olley-Pakes decomposition further shows that improvements in firm-level productivity do not necessarily translate one-for-one into higher aggregate productivity. While average firm-level productivity increases, part of these gains is offset by declining allocative efficiency. This highlights the importance of distinguishing between within-firm productivity effects and changes in the allocation of economic activity across firms.

Finally, the results imply that monetary policy influences not only short-run output and inflation but also firms' longer-run productivity performance. By shaping financing conditions, monetary policy affects firms' ability to undertake productivity-enhancing investments, with particularly strong effects for highly leveraged firms. At the aggregate level, however, these within-firm productivity effects need not translate one-for-one into higher productivity because changes in allocative efficiency may partly offset them.

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Appendix A. Proofs and Derivations for the Theoretical Model

Proposition Appendix A.1. Let $z_t = (e_t, r_t) \in Z \equiv E \times B$ denote the state vector and let $x_t = (\tilde{e}_t, k_t, l_t, s_t, q_t)$ denote the vector of firm decisions in period t , where $q_t \in \{0, 1\}$ is a liquidation indicator. If $q_t = 0$, the firm continues operating and its decisions satisfy Eqs. (1a)–(1h). If $q_t = 1$, the firm liquidates, distributes its remaining equity, and enters an absorbing exit state with zero continuation value.

A feasible plan from an initial state z_0 is a sequence $\{z_t, x_t\}_{t=0}^\infty$ satisfying

$$z_{t+1} \in \Gamma(z_t, x_t),$$

where Γ denotes the state-transition correspondence induced by the operating constraints and the liquidation option.

Let the exogenous interest-rate process $\{r_t\}_{t=0}^\infty$ be given by Eq. (1h), with $\{\epsilon_t\}$ a bounded, mean-zero stochastic process such that $r_t \in B$, where $B \subset \mathbb{R}$ is compact. Define

$$\Pi(z_0) = \{\{z_t, x_t\}_{t=0}^\infty : z_{t+1} \in \Gamma(z_t, x_t), \quad t = 0, 1, \dots\}, \quad (\text{A.1})$$

the set of feasible plans starting from z_0 .

Since liquidation is always feasible, the feasible correspondence is nonempty for every $z_0 \in Z$. Assume further that feasible transitions remain in the compact state space Z and that, for every feasible plan $\{z_t, x_t\} \in \Pi(z_0)$, the discounted return is bounded above.

Then the value function associated with the infinite-horizon problem in Eq. (2), augmented by the liquidation option, is well defined, finite, and uniquely determined. Moreover, at least one optimal feasible plan $\{z_t^*, x_t^*\}_{t=0}^\infty$ exists that attains the supremum:

$$V(z_0) = \sup_{\{z_t, x_t\}_{t=0}^\infty \in \Pi(z_0)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t [(1 - q_t)(e_t - C - \tilde{e}_t) + q_t e_t]. \quad (\text{A.2})$$

Proof. We verify Assumptions 4.3 and 4.4 of [Stokey et al. \(1989\)](#) and then apply their Theorem 4.6. Let the state be $x_t = (e_t, r_t) \in X \equiv E \times B$, where $E \subset \mathbb{R}_+$ and $B \subset \mathbb{R}$ are compact. The control vector is $a_t = (\tilde{e}_t, k_t, l_t, s_t) \in \mathbb{R}_+^4$. We assume that $1 + r > 0$ and $r + \delta > 0$ for every $r \in B$, that $\rho(s)$ is continuous, and that the exogenous interest-rate process is time-homogeneous with a continuous transition law on B .

For each $(e_t, r_t) \in X$, let $A(e_t, r_t)$ denote the set of controls satisfying Eqs. (1a)–(1g). Next-period equity is determined by Eq. (1a). We assume that E is chosen as a viability set, so that feasible equity transitions remain in E . Non-emptiness can be seen constructively. For every $e_t \geq C$, consider

$$\tilde{e}_t = e_t - C, \quad k_t = e_t - C, \quad l_t = s_t = 0.$$

The financing identity then implies

$$b_t = r_{k,t}(k_t - \tilde{e}_t) = 0,$$

so both borrowing bounds are satisfied. The dividend constraint also holds with equality, and $e_{t+1} = (1 - \delta)(e_t - C)$.

By the viability assumption on E , this next-period equity level belongs to E . Hence, $A(e_t, r_t)$ and the induced transition correspondence are nonempty.

We next establish compact-valuedness. The dividend constraint implies

$$0 \leq \tilde{e}_t \leq e_t - C \leq \bar{e} - C.$$

Combining the financing identity with the upper borrowing constraint gives

$$wl_t + r_{k,t}(k_t + s_t) \leq (\chi_t + r_{k,t})\tilde{e}_t.$$

Therefore,

$$0 \leq l_t \leq \frac{(\chi_t + r_{k,t})(\bar{e} - C)}{w}, \quad (\text{A.3})$$

$$0 \leq k_t, s_t \leq \frac{(\chi_t + r_{k,t})(\bar{e} - C)}{r_{k,t}}. \quad (\text{A.4})$$

Since B is compact, $\chi(r)$ is bounded and $r_k(r)$ is bounded away from zero. Hence, all feasible controls belong to a common bounded set. Because the feasible set is defined by continuous equalities and weak inequalities, $A(e_t, r_t)$ is closed and therefore compact.

The transition equation is continuous in the state and controls. Consequently, the induced transition correspondence is compact-valued and has a closed graph. Together with the assumed continuous Markov transition for r_t , Assumption 4.3 is satisfied.

The one-period return function is

$$F(e_t, \tilde{e}_t) = e_t - C - \tilde{e}_t.$$

It is affine and therefore continuous. Moreover, the dividend constraint and compactness of E imply

$$0 \leq F(e_t, \tilde{e}_t) \leq \bar{e} - C.$$

Thus, F is bounded and continuous, so Assumption 4.4 is satisfied.

Since $\beta \in (0, 1)$, Theorem 4.6 of [Stokey et al. \(1989\)](#) applies. The value function

$$V(e_0, r_0) = \sup_{\{a_t\} \in \Pi(e_0, r_0)} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t F(e_t, \tilde{e}_t) \right]$$

is well defined, bounded, and continuous. Moreover, at least one optimal stationary policy exists and attains the value function.

□

Next, we show that our problem does not exhibit a closed-form solution for the policy functions. Starting from the first order conditions in Eq. (4), we now show formally why these conditions

do not yield closed-form policy functions in any reasonably large analytic class for generic parameterizations.

To simplify our analysis, we set $\rho_t(s_t) = A \log(1 + s_t)$, which satisfies $\rho_t''(s_t) < 0$, when $A > 0$ and $s_t \geq 0$. With $\rho_t(s_t) = A \log(1 + s_t)$ we have $\partial_s \rho_t = \frac{A}{1 + s_t}$. Using the labor-capital relation

$$l_t = \frac{1 - \alpha}{\alpha} \frac{r_{k,t}}{w} k_t,$$

and denoting

$$C_t \equiv \left(\frac{1 - \alpha}{\alpha} \frac{r_{k,t}}{w} \right)^{1-\alpha},$$

we obtain

$$k_t^\alpha l_t^{1-\alpha} = C_t k_t.$$

$$k_t^\alpha l_t^{1-\alpha} = k_t^\alpha \left(\frac{1 - \alpha}{\alpha} \frac{r_{k,t}}{w} k_t \right)^{1-\alpha} = C_t k_t.$$

The optimal labor-capital ratio in a Cobb-Douglas setting does not depend on ρ_t , since it cancels out when combining the two FOCs. The s -FOC in Eq. (4c) therefore reads $\frac{\lambda_t A C_t k_t}{1 + s_t} = r_{k,t}(\psi_t + (1 + r_t)\lambda_t)$, hence

$$s_t = \frac{\lambda_t A \cdot C_t k_t}{r_{k,t}(\psi_t + (1 + r_t)\lambda_t)} - 1. \quad (\text{A.5})$$

If the borrowing constraint is nonbinding ($\psi_t = 0$ and $\lambda_t = (1 - \kappa)/(1 - \delta)$), the per-period unknowns (k_t, l_t, s_t) are given in closed form by combining the above relations:

$$k_t = \frac{(1 + r_t)\lambda_t}{A \cdot C_t} (1 + s_t), \quad l_t = \frac{1 - \alpha}{\alpha} \frac{r_{k,t}}{w} k_t, \quad s_t = \frac{A \cdot C_t k_t}{(1 + r_t)\lambda_t} - 1.$$

When the constraint binds, $\tilde{e}_t$ follows from Eq. (1f)

$$\tilde{e}_t = \frac{w l_t + r_{k,t} (k_t + s_t)}{\chi_t + r_{k,t}},$$

and substituting (A.5) and the expressions above into the transition equation (1a) yields a finite algebraic system in (k_t, ψ_t) which can be solved point-wise. However, ψ_t itself must satisfy the Bellman/Euler recursion

$$\lambda_t = \beta \mathbb{E}_t \left[1 + \lambda_{t+1} \frac{\partial g}{\partial \tilde{e}_{t+1}} \right], \quad \lambda_t = \frac{(1 - \kappa) - \psi_t (\chi_t + 1)}{1 - \delta},$$

so the global policy map $\psi(\cdot)$ is the solution to a functional fixed point involving expectations and regime switches. Hence, the multiplier ψ_t is determined by the Bellman equation through a recursive expectation over future states. The resulting policy map is therefore the solution to a nonlinear functional fixed-point problem. Consequently, even with $\rho_t(s_t) = A \log(1 + s_t)$ one generally needs numerical dynamic programming or nonlinear fixed-point iteration to compute

the full policy functions.

Appendix B. Robustness to Alternative Total Factor Productivity Estimators

This appendix examines whether the main empirical findings in Section 5 depend on the choice of the TFP estimator. While the main analysis employs the fixed-effects productivity estimator, Table B.10 re-estimates all specifications using the semiparametric Akerberg-Caves-Frazer estimator (Akerberg et al., 2015). This estimator addresses the simultaneity problem in production-function estimation by controlling for the endogeneity of firms' input choices and is widely used in the productivity literature.

The results closely mirror those reported in the main text. Across all Taylor-rule specifications, increases in the ECB deposit facility rate and contractionary discretionary monetary policy significantly reduce firm-level TFP. The estimated coefficients remain economically similar in magnitude and retain their statistical significance under the alternative productivity measure. Likewise, the estimated effects of financial frictions, macroeconomic controls, and the distinction between direct and total monetary policy effects remain virtually unchanged.

Importantly, the qualitative ordering between direct and total monetary policy effects is preserved under the Akerberg-Caves-Frazer estimator. This indicates that the decomposition of monetary policy effects developed in the main text is not an artifact of the underlying productivity estimation procedure.

Overall, the robustness analysis demonstrates that the paper's conclusions are not driven by the particular method used to estimate firm-level productivity. Instead, the negative effects of contractionary monetary policy and discretionary monetary policy on productivity are robust across alternative TFP estimators.

Table B.10: Monetary Policy Effects on TFP: Using the Akerberg–Caves–Frazer Productivity Estimator

	Taylor Rule 1993		Taylor Rule 1999		First Difference Rule	
	DMP Direct Effects I	DMP Total Effects I	DMP Direct Effects II	DMP Total Effects II	DMP Direct Effects III	DMP Total Effects III
ECB DFR	−0.1298*** (0.0297)	−0.1598*** (0.0307)	−0.1659*** (0.0321)	−0.1973*** (0.0330)	−0.0975*** (0.0279)	−0.1265*** (0.0289)
DMP Taylor 1993	−0.0060*** (0.0007)	−0.0061*** (0.0007)				
DMP Taylor 1999			−0.0069*** (0.0008)	−0.0071*** (0.0008)		
DMP First difference rule					−0.0073*** (0.0008)	−0.0074*** (0.0009)
Leverage ratio	−0.0359 (0.0307)		−0.0362 (0.0307)		−0.0360 (0.0307)	
Cash holdings	0.0800** (0.0339)		0.0799** (0.0339)		0.0799** (0.0339)	
Interest expense ratio	0.1395 (0.1099)		0.1360 (0.1085)		0.1399 (0.1100)	
External fin. dependence	−0.1213*** (0.0175)		−0.1213*** (0.0175)		−0.1213*** (0.0175)	
Net investment ratio	0.0279*** (0.0107)		0.0281*** (0.0107)		0.0280*** (0.0107)	
Δ(Debt) ratio	−0.0000 (0.0000)		−0.0000 (0.0000)		−0.0000 (0.0000)	
Low Default Risk	0.0663*** (0.0056)		0.0663*** (0.0056)		0.0663*** (0.0056)	
HICP core (-1)	−0.0225*** (0.0050)	−0.0269*** (0.0052)	−0.0209*** (0.0049)	−0.0253*** (0.0052)	−0.0201*** (0.0049)	−0.0245*** (0.0052)
Synthetic Energy (-1)	0.0003*** (0.0001)	0.0004*** (0.0001)	0.0004*** (0.0001)	0.0004*** (0.0001)	0.0002*** (0.0001)	0.0003*** (0.0001)
GDP growth (-1)	0.0009 (0.0010)	0.0010 (0.0010)	0.0008 (0.0010)	0.0009 (0.0010)	0.0006 (0.0010)	0.0007 (0.0010)
IYC 10 years	0.0203*** (0.0059)	0.0240*** (0.0061)	0.0324*** (0.0067)	0.0365*** (0.0070)	0.0087 (0.0053)	0.0121** (0.0055)
R-squared	0.94	0.94	0.94	0.94	0.94	0.94
Within R-Squared	0.11	0.02	0.10	0.02	0.11	0.01
Number of obs.	20,473	20,473	20,473	20,473	20,473	20,473
Number of groups	3,876	3,876	3,876	3,876	3,876	3,876
Average. Obs. group	5.28	5.28	5.28	5.28	5.28	5.28
Min. Obs. group	3	3	3	3	3	3
Max. Obs. Group	11	11	11	11	11	11

Source: Own calculations. OeNB. ECB SDW. Bloomberg.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. We use cluster robust standard errors with clustering at the firm level. As a robustness check, we also use two-way clustered standard errors at the firm and year level. Results can be found in the Online Appendix.

The dependent variable is the Akerberg–Caves–Frazer total factor productivity estimator (Akerberg et al., 2015).

We estimate the models “DMP Direct Effects I” and “DMP Total Effects I” with the deviation from monetary policy rules calculated from the Taylor Rule 1993, which is estimated by Eq. (17).

We estimate the models “DMP Direct Effects II” and “DMP Total Effects II” with the deviation from monetary policy rules calculated from the Taylor Rule 1999, which is estimated by Eq. (18).

We estimate the models “DMP Direct Effects III” and “DMP Total Effects III” with the deviation from monetary policy rules calculated from the first difference rule, which is estimated by Eq. (19).

Leverage ratio, cash holdings, interest rate expense ratio, external financial debt ratio, net investment ratio, Δ(Debt ratio) are explained in Section 3.1 and are suggested by the literature to measure financial frictions.

The deviations from monetary policy rules (DMP) either refers to the deviation from Taylor (1993), as defined in Eq. (17), to the deviation from Taylor (1999), as defined in Eq. (18), or to the deviation from the first difference rule, as defined in Eq. (19).

Appendix C. High-Frequency Monetary Policy Shocks and Macroeconomic Controls

A key identifying assumption underlying high-frequency monetary policy shocks is that they represent unexpected policy innovations that are orthogonal to contemporaneous macroeconomic conditions. Under this interpretation, macroeconomic variables should not predict the

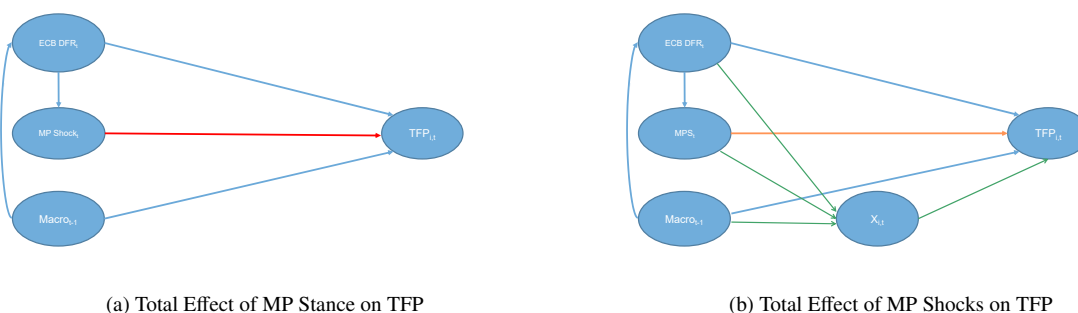
monetary policy shock, implying that they need not be included as control variables in the empirical specification.

However, recent contributions challenge this assumption. [Miranda-Agrippino and Ricco \(2021\)](#) show that commonly used high-frequency monetary policy surprises contain a systematic component that is predictable from publicly available macroeconomic information. Consequently, omitting macroeconomic controls may attribute predictable macroeconomic variation to monetary policy shocks, thereby violating the identifying assumptions implied by the DAG.

To assess the empirical relevance of this issue, we re-estimate the high-frequency specifications without controlling for macroeconomic variables. Figure C.4 illustrates the corresponding identifying assumptions, while Table C.11 reports the estimation results.

Comparing these estimates with the baseline specifications reported in Table 3 shows that the estimated effects of high-frequency monetary policy shocks depend materially on whether macroeconomic controls are included. In particular, the static monetary policy shock becomes considerably larger, whereas the dynamic specification becomes statistically insignificant for the total effect. These differences are consistent with recent evidence that high-frequency monetary policy surprises are not fully orthogonal to macroeconomic information. Accordingly, throughout the main analysis, we include macroeconomic controls to isolate the unexpected component of monetary policy innovations more accurately.

Figure C.4: Total and Direct Effects of Monetary Policy Shocks on TFP



These figures show the DAGs corresponding to our causal models to identify the total and direct effects of monetary policy shocks on TFP. Each variable or variable group is represented by a node (e.g., ECB DFR). The nodes are connected by arrows if we assume a causal relationship. Missing arrows imply the absence of any causal relationship. The left DAG presents the causal model for the total effect. The right DAG shows the causal model for the direct effect.

Table C.11: High-Frequency Monetary Policy Effects on TFP: Sectoral and Fixed Effects Models

High-frequency instrument based on Jarocinski and Karadi (2020) without macro controls				
	Static MPS Direct Effects I	Static MPS Total Effects I	Dynamic MPS Direct Effects II	Dynamic MPS Total Effects II
ECB DFR	−0.0676*** (0.0072)	−0.0799*** (0.0072)	−0.0642*** (0.0077)	−0.0783*** (0.0080)
MPS High-Freq.	−0.0010*** (0.0002)	−0.0011*** (0.0002)	−0.0002* (0.0001)	−0.0001 (0.0002)
Leverage ratio	−0.0455 (0.0332)		−0.0472 (0.0332)	
Cash holdings	0.0617* (0.0330)		0.0618* (0.0330)	
Interest expense ratio	0.1224 (0.1043)		0.1210 (0.1040)	
External fin. dependence	−0.1172*** (0.0167)		−0.1171*** (0.0167)	
Net investment ratio	0.0295*** (0.0105)		0.0297*** (0.0105)	
Δ(Debt) ratio	−0.0000 (0.0000)		−0.0000 (0.0000)	
Low Default Risk	0.0658*** (0.0056)		0.0662*** (0.0056)	
R-squared	0.9494	0.9442	0.9494	0.9442
Within R-Squared	0.1123	0.0212	0.1115	0.0201
Number of obs.	20473	20473	20473	20473
Number of groups	3876	3876	3876	3876
Average. Obs. group	5.2820	5.2820	5.2820	5.2820
Min. Obs. group	3	3	3	3
Max. Obs. Group	11	11	11	11

Source: Own calculations. OeNB. ECB SDW. Bloomberg.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. We use cluster robust standard errors with clustering at the firm level. As a robustness check, we also use two-way clustered standard errors at the firm and year level. Results can be found in the Online Appendix.

The dependent variable is the total factor productivity estimated by the fixed effects model as in [Ernst and Sigmund \(2023\)](#).

Leverage ratio, cash holdings, interest rate expense ratio, external financial debt ratio, net investment ratio, Δ(Debt ratio) are explained in Section 3.1 and are suggested by the literature to measure financial frictions.

The static shock refers to a weighted average of the high-frequency instrument of [Jarocinski and Karadi \(2020\)](#) as suggested by [Albrizio et al. \(2023\)](#). The dynamic monetary shock refers to the cumulative sum of the high-frequency instrument determined in a 12-month rolling window.

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Publisher and editor

Oesterreichische Nationalbank
Otto-Wagner-Platz 3, 1090 Vienna, Austria
PO Box 61, 1011 Vienna, Austria
www.oenb.at
oenb.info@oenb.at
Phone (+43-1) 40420-6666

Editor

Martin Summer

Cover Design

Information Management and Services Division

DVR 0031577

ISSN 2310-533X (Online)