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Endogenous monetary policy effectiveness

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Abstract

How does the effectiveness of monetary policy vary over the policy cycle? Do tightenings and loosenings have symmetric effects on the macroeconomy? This paper addresses these questions using a nonlinear empirical framework that allows financial exposure to evolve endogenously in response to macroeconomic conditions and monetary policy changes. We provide new evidence on how monetary policy effectiveness varies over the policy cycle and across economic states. We find that i) monetary policy transmits more strongly to the real economy in periods of elevated private-sector financial exposure; ii) tightening cycles increase financial exposure in the short run, which in turn amplifies the effect of further interest rate increases, whereas loosening cycles lower financial exposure, increasingly dampening the effect of interest rate cuts; iii) tightening during economic downturns further intensifies debt-servicing pressures, making monetary policy even more potent; instead, when the tightening occurs during expansions, monetary policy effectiveness is not materially affected.

JEL classification: E3, E44, G01, G21
Keywords: Monetary Policy; non-linear models; monetary policy transmission.

Non-technical summary

Since the global financial crisis, central banks have paid close attention to how the private sector's financial exposure shapes the way monetary policy affects the economy. Households and firms that are heavily indebted, or facing rising debt-servicing costs, tend to cut back spending more sharply when interest rates rise. This means that the same change in interest rates can have very different effects on growth, inflation and financial stability depending on how exposed borrowers already are. What has received less attention is that monetary policy itself can change how exposed borrowers are, meaning that a series of rate increases or cuts may gradually change its own effectiveness as it unfolds.

In this paper, we use euro area data to examine how the effectiveness of monetary policy depends on, and in turn shapes, the private sector's financial exposure, measured by its debt-servicing ratio. We build an empirical framework in which financial exposure is allowed to evolve endogenously in response to both economic conditions and monetary policy changes, rather than being treated as fixed. This distinction matters for policy makers because it implies that a sequence of tightening or loosening moves does not simply have a constant effect each time: the potency of policy can build up or fade away as the monetary cycle progresses.

Our findings reveal that monetary policy has a substantially stronger effect on output and inflation when financial exposure is elevated than when it is low. We also find that interest rate increases tend to raise financial exposure in the short run, which makes further tightening increasingly powerful the longer a tightening cycle continues; conversely, interest rate cuts lower financial exposure over time, so that a loosening cycle becomes progressively less effective the longer it continues. The size and speed of a tightening or loosening cycle reinforce this pattern: faster and larger changes in interest rates bring about the change in effectiveness more quickly.

Our findings also reveal that a tightening cycle leaves the economy more sensitive to other shocks, such as a fall in house prices or a broader downturn in demand, whereas a loosening cycle reduces the effects that these shocks have on the economy. However, this state dependence is not simply mechanical: whether a tightening episode heightens financial exposure depends also on the economic environment. When a tightening takes place alongside an economic expansion, the improvement in incomes tends to offset the higher cost of debt, leaving financial exposure, and the effectiveness of policy, broadly unchanged. When a tightening instead coincides with an economic downturn, financial exposure increases materially, and the impact of monetary policy on output, inflation and financial stability risk is amplified further.

Overall, our findings suggest that policymakers should be attentive not only to the current state of private-sector financial exposure when calibrating monetary policy, but also to how a given policy path will itself alter that exposure, and hence the effectiveness of future interest rate changes. A rate increase taken late in a tightening cycle, or one that coincides with a weakening economy, is likely to have a stronger effect than an equivalently sized move taken earlier or against a healthier economic backdrop.

1. Introduction

A large body of research emphasizes the role of balance sheets in shaping the transmission of monetary policy. When the private sector is highly leveraged or faces binding debt-servicing constraints, increases in interest rates can generate disproportionately large effects on consumption. Early contributions emphasize the balance-sheet and credit channels, whereby monetary tightening weakens borrowers' net worth, amplifying real effects when financial conditions are tight (Bernanke and Gertler [1995]). More recently, heterogeneous-agent models have shown that the macroeconomic response to monetary policy depends critically on the distribution of the private sector's assets and liabilities: the policy transmission is stronger when a larger share of households is financially constrained and exhibits high marginal propensities to consume (Kaplan et al. [2016]). Consistent with the theoretical work, central bank analyses have shown that economies with higher financial exposure (gauged by debt-servicing ratios or leverage ratios) experience stronger consumption and output responses to monetary policy shocks (Lane [2019]; Cumming and Hubert [2019]). Much of the existing empirical literature, however, treats financial exposure as an exogenous variable, abstracting from the possibility that monetary policy may alter financial exposure over the policy cycle. This raises a set of closely related questions on the transmission of monetary policy: how does financial exposure vary with monetary policy changes? Do tightenings and loosenings have symmetric effects across different phases of the economic cycle?

This paper addresses these questions using a Multivariate Smooth-Transition Local Projection (MSTLP) model in which financial exposure — measured by the debt-servicing ratio (DSR) of the non-financial private sector — serves both as an endogenous variable and as the state variable governing the regime of the economy. This dual role is the key innovation of the framework: by allowing the DSR to respond to macroeconomic conditions and monetary policy shocks, the model captures how monetary policy can alter the state of the economy in future periods and thereby affect its own future effectiveness— an amplification mechanism that linear models or models with exogenous state variables abstract from. Specifically, the transition variable z_t is a function of past values of the DSR, so that current shocks affect the regime prevailing in subsequent periods rather than instantaneously.[1] Concretely, we use the MSTLP model to

[1]Monetary policy shocks are identified through a structural Cholesky decomposition using the variance-covariance matrix of the reduced form errors estimated at the first horizon of the projections. We assess the robustness of this identification strategy using the high-frequency monetary policy shock of Jarociński and Karadi [2020] as an external instrument.

estimate the impact of monetary policy on a set of macroeconomic and financial variables in the euro area. The non-linear structure of the model allows the dynamic impact of monetary policy to depend on the evolution of financial exposure. By influencing financial exposure, monetary policy has implications for its own effectiveness in subsequent periods. The inclusion of financial indicators in the set of endogenous variables (for example, expected default frequency of banks or EDFs) also allows us to assess the implications of these changes in monetary policy effectiveness for financial stability. We employ a local projection framework, which offers robustness to misspecification and accommodates the nonlinear, endogenous state variable in a tractable way.

We conduct four exercises. In a first exercise, we use the model to study how monetary policy shocks propagate under different degrees of financial exposure. We find that when financial exposure is high, the impact of a monetary policy change on inflation and activity is substantially stronger than when financial exposure is low.[2]

In a second exercise, we study how the monetary policy cycle itself affects the effectiveness of subsequent monetary policy changes. Importantly, changes in the short-term rate also trigger a mechanical change in debt-service ratios by altering the effective lending rate applicable to borrowers with adjustable-rate loans. To assess the importance of this effect, we consider two alternative monetary policy paths, a tightening and a loosening of the same size and length (the only difference is the sign). We find that monetary policy shocks coming at the end of the tightening cycle have a significantly stronger effect than monetary policy changes happening at the end of a loosening cycle. This is because, in the short run, a tightening cycle increases the debt-service ratio of the economy, making any marginal tightening even more impactful. In contrast, during a loosening cycle, monetary policy reduces its effectiveness, as the debt-servicing ratios decrease, making spending decisions less sensitive to monetary policy changes. The estimates also uncover a size effect: by considering tightenings or loosenings of different sizes, we find that the changes in monetary policy effectiveness are stronger if the monetary cycles are steeper, that is, the variation of short-term rate is faster. The empirical model also includes financial variables, allowing us to assess their response to monetary policy. The estimates indicate that banks' expected default frequencies (EDF) tend to increase more following a contractionary monetary policy shock when financial exposure is high, though the state-dependent effect on the median EDF is relatively contained. The lack of response in the median probably owes to the influence of different factors affecting bank profitability. Borio et al. [2017] find that tightenings increase banks' profitability via an increase in lending margins, whereas Altavilla et al. [2018] find that

[2] This result is in line with Alpanda et al. [2021] and contrasts with the findings in Aikman et al. [2020].

loosenings can increase bank profitability as the negative effect of lower margins is counteracted by better economic performance, lower credit losses and higher non-interest income. In the appendix we also show that the effect on EDF dispersion across banks is significant: in the high financial exposure state, a monetary policy shock can increase the dispersion in EDF across the banking system, hitting more than proportionally the EDF of high-risk banks. This result is in line with the structural model inHerrera et al. [2026], where monetary policy tightening increases banks' probability of default more when households are highly leveraged.

In a third exercise, we explore whether a monetary policy cycle also changes the sensitivity of the economy to other economic shocks. We find that housing market shocks and output shocks are amplified when these shocks take place after tightening cycles, while the amplification is muted when the shock follows a loosening cycle.[3] Similarly, the expected probability of bank defaults increases significantly more when a monetary policy tightening follows a tightening cycle vis-a-vis a loosening one. In the short run, a tightening cycle can thus increase the sensitivity of the economy to other shocks.[4] While our analysis focuses on the short-term, a policy maker would need to weigh these results against medium-term effects of tight monetary policy, which should in general lead to deleveraging and an eventual fall in debt-service ratios.

In a final exercise, we explore the interaction between the monetary policy cycle and the state of the economy. To do that, we simulate different tightening scenarios. In the first (second) scenario, the tightening happens during an economic expansion (recession), generated by a combination of output and monetary policy shocks over the first four quarters. In a third scenario, the tightening happens in a neutral environment (only monetary policy shocks produce the tightening). We find that if the tightening happens in an expansionary phase, the increase in lending rates propelled by the higher short-term rates is offset by the increase in nominal output, the denominator of the debt-service ratio. As a result, the effectiveness of monetary policy remains broadly stable with respect to the beginning of the tightening. In a recessionary phase, debt-service ratios are substantially increased by both the rise in short-term rates and the reduction in nominal output. In this case, the monetary policy impact on inflation and activity is substantially strengthened with respect to the starting point. In this case, the responses of EDFs also become more sensitive, implying stronger effects on financial stability risks. The

[3] In the model, we identify a housing shock as an exogenous variation in housing preferences triggering a decrease in house prices on impact and transmitting to the rest of the economy. The output shock is an exogenous shock to output allowed to have an impact on all the variables of the model. In our estimates, the output shock produces an effect of the same sign on output and inflation, in line with standard dynamics of a demand-side shock.

[4] In the appendix, we find that the effect is one order of magnitude higher on EDF dispersion, i.e. the difference between the 90th percentile and the median EDF.

third, neutral scenario, lies in between the two extremes.

To summarise, the four key findings are: i) monetary policy is more impactful when financial exposure is elevated; ii) monetary policy tightenings increase financial exposure in the short run, making monetary policy more impactful over a tightening cycle; iii) the effect of real and financial shocks is amplified after a tightening cycle and reduced after a loosening one; iv) when the tightening happens during downturns, monetary policy effectiveness is even stronger, whereas the opposite holds if the tightening happens during expansions.

Literature review Previous work has highlighted that monetary policy effectiveness can vary across different phases of the business cycle or of the financial cycle (Alpanda et al. [2021], Tenreyro and Thwaites [2016]). The key innovation in our paper is to allow the state variable, financial exposure, to also evolve endogenously both in response to macroeconomic conditions and to monetary policy changes, thus affecting the effectiveness of the monetary policy transmission. Our paper relates to recent work by Cumming and Hubert [2023], who find that monetary policy is more effective when the share of highly indebted households in the economy is large. We allow for that indebtedness to respond to monetary policy. In our model, the effectiveness of monetary policy can vary with the state of the business cycle as in Tenreyro and Thwaites [2016]. In our paper, the key state variable is financial exposure, and the model includes other financial variables, allowing us to explore the link between the level of interest rates and the business cycle. Critically, in our setting the state variable is also function of other endogenous variables. This implies that monetary policy can change the state variable over time, influencing its own effectiveness over the monetary policy cycle. To the best of our knowledge, we are the first to allow the state variable to endogenously evolve with incoming shocks in a LP framework; this allows us to explore how tightening or loosening cycles can affect monetary policy effectiveness. Since in our models all the shocks concur to determine the evolution of the state variable, we can also jointly study how monetary cycles, financial and business cycles conditions affect the effectiveness of monetary policy. This enables us to estimate sign- and size-dependent effects. The sign effects owe to the fact that following tightening cycles, monetary policy becomes more powerful, whereas the opposite is true following loosening cycles. The size effects owe to the fact that a steep tightening or loosening can influence monetary policy's future effectiveness more abruptly.

Our work provides supporting evidence to models with financial accelerators (Bernanke et al. [1999], Guerrieri and Iacoviello [2017], Jensen et al. [2020], Justiniano et al. [2015, 2019], Kiyotaki and Moore [1997], Liu et al. [2013]). In these models, agents are subject to leverage constraints. By affecting their leverage constraints, shocks can affect agents' spending decisions, amplifying the initial effect of the shocks. In these models, the more agents are indebted or constrained, the stronger is the impact of monetary policy tightenings. The amplification results in our estimates are consistent with these structural models findings.

Our findings relate to a stream of literature that studies how monetary policy affects financial conditions and the financial cycle (Adrian and Liang [2016], Chavleishvili et al. [2023], Filardo et al. [2022], Natvik et al. [2018], Schularick and Taylor [2012]). We study how monetary policy affects the evolution of the debt-servicing ratios of non-financial companies and banks' EDFs. We find that monetary policy has relatively small effects on the median EDF. However, the effects are highly heterogeneous: by comparing the impact on the 90th percentile and the median EDFs, we find that the increase in financial stability risks for the higher EDF bank is substantial, particularly when the increase in interest rates follows a tightening cycle. Finally, monetary policy tightenings lead to further amplification of future recessionary shocks, such as housing market or aggregate demand shocks.

The paper is organised as follows. Section 2. presents the econometric model and Section 3. describes the data used for the estimation. Section 4. presents the baseline results, discussing how the impact of monetary policy varies with the extent of financial exposure. Section 5. studies how the effectiveness of interest rate changes depend on the phase of the monetary policy cycle and Section 6. studies how that effectiveness varies with the interaction between the business and monetary policy cycles. Section 7. concludes.

2. Econometric model

We employ a macroeconomic model with multivariate smooth-transition regime switching (Auerbach and Gorodnichenko [2013], Couaillier and Scalone [2024], Tenreyro and Thwaites [2016]) and estimate it using a local projections (LP) approach, as in Jordà [2005]. In the model, the economy transitions between two states. Shocks can propagate differently in the two states. The transition between states is smooth and depends on the evolution of a state variable. Moreover, the state variable is a function of an endogenous variable, implying that shocks also affect the state of the economy and the propagation of shocks coming in the following periods.

The econometric model is represented as:

$$\begin{aligned} Y_{t+h} = \; & F(z_t)(\alpha_h^U + \beta_h^U Y_t + \Sigma_{\ell=2}^p L_{h,\ell}^U Y_{t-\ell}) \\ & + (1 - F(z_t))(\alpha_h^D + \beta_h^D Y_t + \Sigma_{\ell=2}^p L_{h,\ell}^D Y_{t-\ell}) \\ & + u_{h,t}, \end{aligned} \tag{1}$$

$$z_t = f(Y_{t-1}, Y_{t-2}, Y_{t-J}) \tag{2}$$

where Y_t is the $(n, 1)$ vector of endogenous variables at time t, with $t = 0, ..., T$ indicating the period in which the shock took place and $h = 0, ..., H$, the horizon following the shock; p indicates the number of lags. The key novelty of the model is that z_t, the scalar state variable at time t, is a function of the past values of a set of Y_t. $u_{h,t}$ is the $(n, 1)$ vector of errors at horizon h at time t. In particular, in our specification, the debt-servicing ratio is both an endogenous variable and a state variable. The state-dependent effect is determined by $F(z_t)$, which is a scalar function governing the transition between the two regimes. This function is a logistic transformation normalizing the state variable as a scalar included in the interval $[0, 1]$. Higher values of z_t correspond to $F(z_t)$ closer to 1, making Y_{t+h} depend more on the first line of Equation 1. Accordingly, superscript U denotes the high-exposure regime ($F(z_t)$ close to 1), in which the debt-servicing ratio is elevated and rising, while superscript D denotes the low-exposure regime ($F(z_t)$ close to 0).[5] The transition function is the logistic transformation of the original z_t:

$$F(z_t) = \left(1 + exp\left\{ -\theta\left(\frac{z_t - c}{\sigma_z}\right)\right\}\right)^{-1} \tag{3}$$

where θ is the smoothing parameter influencing the smoothness of the transition from one state to another,[6] c determines the part of the sample spent in either state,[7] and σ_z is the standard deviation of the observed state variable. Both parameters are calibrated (Auerbach and Gorodnichenko [2013]). We set c at the historical median of the original state variable, so that the resulting state spends half of the time in both regimes. Our baseline specification uses $\theta = 3$ (Tenreyro and Thwaites [2016]), but our results are robust to a large range of calibrations, as we document in Table F.1 in the Appendix F.

The choice of a local projection framework over a VAR offers several advantages in this setting. First, LPs are robust to misspecification of the data-generating process (Jordà [2005]),

[5]For parsimony, we assume that the lag coefficients $L_{h,\ell}^U$ and $L_{h,\ell}^D$ are common across the two regimes. This restriction reduces the number of parameters to estimate given the limited sample size.

[6]The higher θ, the faster $F(z_t)$ goes toward 0 and 1, i.e. converging to a threshold switching model.

[7]$z_t > c$ is equivalent to $F(z_t) > 0.5$. Defining c as the $p - th$ quantile of the historical time series of z_t forces $F(z_t)$ to spend $p\%$ of the time below 0.5, i.e. in the low regime.

which is particularly valuable here given the nonlinear structure of the model and the endogenous treatment of the state variable — both of which would impose stronger specification requirements in a VAR setting. Second, the LP approach allows for a relatively transparent and flexible way to obtain impulse responses in a non-linear framework, including the endogenous transition variable: since each horizon is estimated as a separate projection, the state variable can be updated between successive shocks in the simulated cycle as a function of accumulated endogenous responses, without taking a stand on the full joint dynamics of the system. Within the impulse response horizon of each individual shock, the state variable is held fixed at the value prevailing at the date of impact.

We construct confidence intervals using the block-of-blocks bootstrap approach, following Kilian and Kim [2011], in order to account for autocorrelation in the time series.[8]

In our baseline framework, structural shocks are identified via a Cholesky decomposition of the variance-covariance matrix of the reduced-form residuals at the first horizon of the local projections and are then propagated over time through the LP coefficients estimated at each horizon. Concretely, structural shocks affect the endogenous variables on impact, through the impact matrix Ξ_1, and their immediate effect propagates at horizon h, through the local projection coefficients β_h^D and β_h^U. For each projection horizon $h = 1, ..., H$, the impulse response function (IRF) is:

$$\begin{aligned} IRF_{h,t} = E_t(Y_{t+h}|Y_t + \Xi_1\epsilon_t) - E_t(Y_{t+h}|Y_t) = \\ F(z_t)(\beta_h^U\Xi_1\epsilon_t) + (1 - F(z_t))(\beta_h^D\Xi_1\epsilon_t). \end{aligned} \tag{4}$$

The state of the economy z_t determines how the shock propagates, affecting the relative weight in each impulse response in the two states of the economy. We assess the robustness of this identification strategy in Section 4., where we replicate the main results using the high-frequency monetary policy shock of Jarociński and Karadi [2020] as an external instrument, purged of central bank information effects. The shock is constructed from financial market surprises around ECB Governing Council meetings compiled by Altavilla et al. [2019].

In this work, we compare how the transmission of shocks changes across the monetary and business cycles in two steps. First, we show how the cycles affect the economy, and thereby

[8]We construct all possible overlapping tuples of m consecutive dates in the matrix Y of endogenous variables, along with the corresponding block of regressors for each selected dates, at each horizon of regression. We then draw in this set of blocks to construct the bootstrapped time series. We set $m = 5$ in line with Horowitz [2019], in that m should be proportional to $n^{1/3}$. We thus select blocks of five consecutive dates to build the bootstrap time series. In a robustness exercise, we also apply the bootstrap-after-bootstrap method, which corrects for bias in bootstrap estimates (see Kilian [1998], Kilian and Kim [2011]).

financial exposure, over time. Second, we compare how monetary policy shocks hitting the economy at different moments of the cycle transmit to the economy. The dynamic response of the economy along a monetary policy cycle is obtained by summing the IRFs of all shocks hitting the economy over the cycle, each evaluated at the horizon corresponding to the time elapsed since the shock occurred and at the value of $F(z_t)$ prevailing at the time of that shock:

$$Y_{t+h}^{cycle} = \sum_{j=0}^{h} IRF_{h-j,\,t+j} \tag{5}$$

where $IRF_{h-j,\,t+j}$ denotes the impulse response at horizon $h-j$ of the shock arriving at time $t+j$, computed using $F(z_{t+j})$ at that date, as in equation 4. This approach allows $F(z_t)$ to update endogenously as the cycle progresses in line with equation 2, capturing how the state of the economy evolves in response to the cumulated monetary policy shocks. In the second step, we assess how the cycle affects the effectiveness of monetary policy by comparing the IRFs in equation 4, computed conditional on the value of financial exposure prevailing at the moment when the monetary policy shock hits the economy – for example, at the beginning or at the end of the cycle. Concretely, the cycle simulation proceeds as follows. Starting from an initial DSR level, at each step j of the cycle a structural shock hits the economy. The state variable z_{t+j} is updated using the accumulated LP-predicted DSR responses from all previous shocks in the cycle, as described in Section 3.. The value of $F(z_{t+j})$ implied by this updated state is then used to compute the impulse response of the shock hitting at step j, via equation 4. Within the impulse response horizon of each individual shock, the state variable is held fixed at the value prevailing at the date of impact. The accumulated DSR response is then updated with the LP-predicted DSR path of the current shock, and the procedure repeats for the next step.[9]

3. Data

We estimate the model on euro area data (EU19). Our sample ranges from 2001 Q1 to 2019 Q4. As shown in the Appendix E, our key results are confirmed if we estimate the model including observations until 2023 Q4 (Figure E.5). The set of endogenous variables includes gross domestic product (GDP), consumer price inflation (HICP), the ECB commodity price index (CPI), the short-term rate (3-months EURIBOR), the median expected default frequency

[9] As a robustness check, we re-estimate the cycle exercises using a version that additionally updates $F(z_t)$ at each horizon within each individual shock's response window, rather than only between successive shocks as in the baseline. To ensure comparability, we recalibrate the shock sequence so that the policy rate follows the same path across the two specifications. The results between the two approaches are quantitatively very close.

(EDF) of euro area banks within one year, house prices, and the debt service ratio of the non-financial private sector. Interest rates and the EDF are reported in levels, whereas the other variables are expressed in percentage quarterly variations. The DSR is expressed in two-year differences. The process has one lag and the model is estimated for 12 quarters ahead.

The inclusion of financial variables in the model allows us to control for the role of financial factors in the propagation of monetary shocks. We can also assess how monetary policy affects financial stability across the different states of the economy. Banks' EDF within one year are estimated by Moody's Analytics using the KMV model.[10] In our baseline estimation, we use the median EDF quarterly series to capture information on the evolution of the financial stability risk of the median bank.[11] In robustness exercises in the Appendix, we also consider alternative measures of default: i) the average EDF, computed by weighting each bank according to its asset size; ii) the difference between the 90th percentile and the median EDF, which allows us to gauge systemic risk across the banking system; iii) the spread between the long term 10 year rate and the short-term rate. Our results are robust to these different measures of financial risks. House prices are measured as the residential real estate price index, expressed in real terms and quarterly percentage variation.

Following Christiano et al. [1999], we include a commodity price index, which substantially reduces the price puzzle, that is, the increase in inflation following a monetary policy shock in the first part of the projection. We use the import-weighted ECB commodity price index.[12] In robustness exercises, we consider alternative measures of commodity price indexes (e.g. use-weighted ECB commodity price index, Energy commodity prices).

The debt service ratio (DSR) of the Non-Financial Private Sector, is computed in line with Drehmann et al. [2015]:

$$DSR_t = \frac{D_t}{Y_t} \frac{i_t}{1-(1+i_t)^{-m}}, \tag{6}$$

where Y_t is nominal GDP (4-quarters rolling sum), D_t is total credit to the non-financial private sector (loans and debt securities from the ECB Quarterly Sector Account, QSA), i_t is a weighted average of the lending rates to firms and to households from the ECB MIR dataset; m is the average maturity of the total debt in the economy, computed using the ECB Balance Sheet Items dataset (BSI). The DSR is the fraction of revenues that agents have to pay in the current

[10] In the KMV model, using an option pricing approach, banks market value, banks' asset volatility and banks leverage jointly determine the distance to default.

[11] The median and the 90th percentiles are computed by the ECB and included in the ECB Statistical Data Warehouse: respectively $KMV.M.I7.Z0Z.4F.EDF01.SCT_FIN.MED$, $KMV.M.I7.Z0Z.4F.EDF01.SCT_FIN.90P$.

[12] ECB Commodity Price index, import weighted ($STS.M.I9.N.ECPE.CTOTNE.3.000$).

period in order to repay a debt of m maturity in equal portion.

The use of the two-year difference of the DSR, rather than its level, reflects the macroprudential rationale for the state variable. A high but stable DSR indicates that households and firms have already adjusted to their debt-servicing burden and are unlikely to face acute liquidity constraints in response to a further tightening. By contrast, a rapidly rising DSR signals a deterioration in debt-servicing capacity that has not yet been fully absorbed, generating greater vulnerability to monetary policy shocks. This distinction is consistent with the macroprudential literature, which uses the two-year change in the DSR as an early warning indicator of cyclical financial risk [Drehmann and Juselius, 2012, Drehmann et al., 2015, Lang et al., 2019]. In this sense, z_t captures the build-up of financial exposure rather than its level, and the high-exposure regime identifies periods in which the financial cycle is in an expansionary or deteriorating phase. As a robustness check, Appendix A replicates the main results using the DSR in levels as the state variable instead of the two-year difference; the state-dependent amplification pattern is qualitatively confirmed.

As noted above, the DSR is used both as a state variable and as an endogenous variable. For the state variable, we compute the linear moving average of the DSR-2Y with a window of seven periods, in line with Tenreyro and Thwaites [2016]. Specifically, z_t is defined as:

$$z_t = \sum_{k=0}^{6} w_k \Delta_8 DSR_{t-k} \tag{7}$$

where $\Delta_8 DSR_{t-k}$ denotes the two-year difference of the DSR at lag k, and the weights $w_k = (7-k)/28$ are linearly declining so that more recent observations receive higher weight. The moving average allows us to make the evolution of the state variable more stable over time, reducing the possibility that occasional and temporary jumps might be excessively weighted in the estimation. More recent observations receive a higher weight. A positive value implies that the average DSR overall increased in the last two years and that agents are more exposed to economic and financial shocks. Figure 1 shows the evolution of the DSR (blue line) and its logistic transformation (red line). Financial exposure reaches its highest levels in the periods preceding and following the global financial crisis and around the sovereign debt crisis, while remaining comparatively lower after 2014. The high-exposure regime ($F(z_t) > 0.80$) covers 26 observations (36.6% of the sample), concentrated in two distinct episodes: the pre-Global Financial Crisis build-up (2004Q2–2008Q3) and the euro area sovereign debt crisis (2010Q3–2011Q4). The low-exposure regime ($F(z_t) < 0.20$) covers 3 observations (4.2% of the sample), reflecting the fact that the post-2012 deleveraging phase, while sustained, was moderate in pace relative to the pre-crisis build-up. This asymmetry is consistent with the well-documented pattern of rapid debt accumulation followed by slow deleveraging in the euro area financial cycle. In the smooth-transition framework, identification of each regime relies not only on observations at the extremes of $F(z_t)$ but also on the broader set of observations with intermediate state values, which receive weights proportional to their distance from the threshold.

As we show in Section 4., a monetary policy tightening increases the DSR ratio, via an increase in the short-term rate which is transmitted to the effective lending rate of the economy. In Section 5. we show that this effect is key to assess how the monetary policy effectiveness changes over the tightening or loosening cycles. Since the DSR is also endogenously affected by the evolution of output, changes in aggregate demand also affect the denominator of the ratio. This mechanism is underscored in Section 6., where we explore how monetary policy effectiveness changes across different business cycle conditions (expansions or recessions). In the case of expansions, the tightening can increase the numerator via the increase in the short-term rate, whereas the expansion of output can boost disposable income, hence the denominator. As a result, the evolution of the DSR and of the state variable is materially different from the case of a tightening happening during recessions, where the numerator increases and the denominator shrinks.[13] By expressing the DSR in two-year differences, we eliminate low frequency movements.

3.1 Structural identification

We apply a Cholesky decomposition to identify monetary policy shocks recursively. We order variables as follows: output, HICP inflation, Commodity Price Index (CPI), the policy rate, EDF, house prices and DSR. In this ordering, macroeconomic variables are assumed to react to monetary policy with a lag, while financial variables react on impact. The ordering of the short-term rate is such that monetary policy responds on impact to output and prices but not to financial variables, which is standard in the literature on monetary policy identification (Christiano et al. [1996], Goodhart and Hofmann [2008]). In line with the literature on the price puzzle, the inclusion of the commodity price index is important to obtain a negative reaction of inflation to the monetary policy shock (Christiano et al. [1999], Rusnák et al. [2013]). House prices are ordered after the policy rate and EDF, consistent with treating them as asset prices

[13]The use of the DSR allows us to directly capture different dimensions of financial exposure, such as the evolution of the cost of debt, the amount of debt in the economy and the capacity to repay the debt via income. This indicator expressed in difference is widely used in macroprudential analysis to detect the build-up of cyclical risks (Lang et al. [2019]).

that react on impact to all other variables in the system, following Cesa-Bianchi [2013]. The sign of the responses and the state-dependent amplifications are robust to alternative Cholesky orderings. As a robustness check, we show in Section 4. that the state-dependent amplification pattern is qualitatively unchanged when shocks are instead identified via the high-frequency instrument of Jarociński and Karadi [2020], purged of central bank information effects.

4. Effectiveness of monetary policy depending on the degree of financial exposure

In this section we study the macroeconomic response to a monetary policy shock in the linear and in the nonlinear specifications of the model. In order to compare the effectiveness of monetary policy across different states of the economy, we condition the reaction of the policy rate (the impulse variable) to be similar across the two states. We find that the economic responses to the monetary policy shock under elevated financial exposure are close to the ones obtained in the linear case, whereas the economic responses under low financial exposure are milder and often not statistically significant. The responses under the median financial exposure case lie in between the minimum and the maximum financial exposure cases. Conditioning the policy rate to be the same across the different states for the first year of the projection, the nonlinear effects become even stronger. Importantly, the policy rate increase also triggers an increase in the DSR, that is, the state variable. Such an increase will be explored further in Section 5. to assess how monetary cycles can affect the effectiveness of monetary policy through the endogenous reaction of the state variable to past monetary policy shocks.

4.1 Linear dynamics

The first column of Figure 2 displays the estimated IRFs of the economy under a linear framework that constrains the responses to be the same across the different states of the economy. In this specification, the monetary policy shock has a standard effect on the endogenous variables. A one standard deviation policy rate shock increases the policy rate on impact by 20 basis points. The effect decays over time, eventually turning negative. Output and inflation fall over time. The maximum negative effect on output is - 60 basis points and is reached four quarters after the shock. The peak inflation response is - 40 basis points. House prices fall, reaching a peak effect of - 70 basis points nine quarters after the shock, and the EDF increases by 2 basis points two years after the shock. The DSR increases , with a peak effect of 10 basis points a quarter after the shock. The evolution of the DSR mimics the path of the short-term rate, reflecting the fact that a fraction of outstanding loans automatically tracks the short-term rate.

4.2 Nonlinear dynamics

The second column of Figure 2 displays the estimated IRFs from the nonlinear specification. The plot shows the responses to a one standard deviation shock in the case of maximum financial exposure, ($F(z_t) = 1$, red lines), in the median case ($F(z_t) = 0.5$, yellow lines), and in the case with minimum financial exposure ($F(z_t) = 0$, blue lines). Comparing these extreme cases allows us to illustrate the state-dependent effects deriving from the nonlinear structure of the model. For output and inflation, under the maximum exposure case, the responses of the economy are in line with the ones obtained under the linear case. The policy rate increases quickly and soon turns to negative territory until the end of the projection. In this case, the EDF increase is similar to the one obtained under the linear case. House prices decrease by 30 basis points, about half the decrease in the linear specification. In the case of minimum financial exposure (blue line), the responses of output and inflation are close to insignificant. The effect on EDF is now negative in the second part of the projection, though statistically significant only at the end of the projection. The house price response is close to the one obtained under maximum exposure, though it is no longer statistically significant. Finally the effect on the DSR is positive and remains higher over the projection horizon, in line with the evolution of the short-term rate under the minimum financial exposure case. A key challenge with these comparisons is that the policy rate behaves very differently across the specifications. To facilitate the comparison, the third column of Figure 2 displays the estimated IRFs, conditioning to the same evolution of the policy rate during the first year following the shock. This is implemented by adding compensating monetary policy shocks at each quarter of the conditioning window, calibrated so that the cumulative policy rate response is identical across the three exposure levels. After the 1-year conditioning window, the policy rate is left free to respond endogenously. The exercise isolates the state-dependent amplification abstracting from the differential endogenous monetary policy response that arises under different levels of financial exposure.[14] By conditioning the policy rate path over the first year, we find that the response of output and inflation under maximum financial exposure is substantially higher than under the minimum financial exposure case. In particular, output and inflation both decrease by -1.3% at peak, that is, reaching peaks that are more than four times higher than under the minimum financial exposure case for output and

[14] The conditioning applies only to the first four quarters. Beyond that horizon, the policy rate adjusts endogenously. The more negative policy rate response visible after year one under maximum financial exposure reflects the stronger recessionary effect, which triggers a larger endogenous monetary policy easing

more than doubled for inflation. Similarly, the effect on house price is substantially stronger under the maximum financial exposure scenario and more than doubled with respect to the minimum financial exposure case. The estimates also yield a stronger increase of the EDF in the second part of the projection. Conditioning on the same path for the policy rate in the first year of the projection, the DSR increases in a similar way across the three states. In the second part of the projection, when the short-term rate is left free to move, both the short-term rate and the DSR substantially decrease under the maximum financial exposure case, given the stronger endogenous reaction of monetary policy needed to offset the larger contraction in economic activity and inflation. Figure 3 directly tests whether the state-dependent amplification documented in Figure 2 is statistically significant. It reports the difference between impulse responses in the high-exposure state ($F(z_t) = 1$) and the low-exposure state ($F(z_t) = 0$), with 67% bootstrap confidence bands constructed from the joint distribution of the difference within each bootstrap draw. The difference is statistically distinguishable from zero for output and inflation at horizons 3–6, and for the policy rate, EDF, and DSR over the full projection horizon, confirming that the state-dependent differences in impulse responses are statistically significant. Appendix Figure G.6 replicates Figure 2 reporting 90% confidence bands (instead of 67% in the main text) and showing only the high- and low-exposure cases for clarity. The state-dependent differences in impulse responses remain visible at the 90% level, particularly for output, inflation.

As a robustness check on the identification strategy, we replicate the baseline impulse response analysis using an external instrument approach. Specifically, we replace the Cholesky-identified monetary policy shock with the MP shock of Jarociński and Karadi [2020], constructed from high-frequency surprises in overnight index swap rates around ECB Governing Council meetings. This shock is purged of the central bank information component – the component of policy announcements that conveys the ECB's assessment of the economic outlook and that, if left unaccounted for, would bias inference on monetary policy non-neutrality. We aggregate the monthly shock series to quarterly frequency by summing surprises within each quarter, and normalise the resulting series to unit standard deviation. Figure 4 reports the state-dependent impulse responses under this alternative identification. The pattern of amplification across financial exposure states is qualitatively consistent with the baseline: the response of output and inflation is substantially larger under high financial exposure than under low financial exposure, with the median state lying between the two. Confidence bands are of comparable width to the baseline, confirming that the external instrument approach does not substantially reduce estimation precision in this sample.

The stronger amplification of monetary policy when financial exposure is high is consistent with results in Alpanda et al. [2021] and can be explained by structural models featuring a financial accelerator (Guerrieri and Iacoviello [2017], Kiyotaki and Moore [1997]). In those models, households borrowing capacity is constrained by their assets, which are used as collateral. Shocks hitting the value of that collateral can therefore mechanically affect borrowers' debt capacity, amplifying the initial shock. In these models, the larger the debt, the larger the financial accelerator amplification. Conversely, with low indebtedness, the borrowing constraint is slack, and the financial accelerator plays a muted role.

5. Effectiveness of monetary policy over tightening and loosening cycles

This section studies how monetary policy cycles affect the effectiveness of monetary policy: changes in monetary policy influence the evolution of debt-servicing ratios over tightening and loosening periods, thus affecting the state-dependent effects of subsequent monetary policy changes. We first show that the nature of the monetary policy cycle (loosening versus contraction) affects its future effectiveness (sign-dependent effect). In particular, during a tightening cycle, the DSR increases, and so does the monetary policy effectiveness over the cycle. The opposite is true during a loosening cycle. Next, we show that the size of the tightening affects the size of the increase in monetary policy effectiveness (size dependent effect). A tightening can make monetary policy shocks increasingly more effective at stabilising inflation, at the cost of increasingly more recessionary effects on output and financial stability risks. In contrast, over a loosening cycle, monetary policy reduces its capacity to affect inflation and output; the reduction in financial stability risks are larger at the beginning of the loosening cycle. The estimates also indicate that a steeper tightening or loosening accelerate the changes in effectiveness over the monetary cycle (size effect).

5.1 The sign-dependent effect

The first column of Figure 5 displays in red (blue) lines the dynamics of a monetary policy tightening (loosening) of 1 percentage point phased-in over 4 quarters. This exercise assumes that the monetary policy tightening is exclusively generated by monetary policy shocks, meaning that all the policy rate variation in the projections can be interpreted as the result of a deviation from the endogenous policy rate evolution implied by the model. We also assume that at the beginning of each cycle, the economy is at its median state ($F(z_t) = 0.5$). The exercises in the second and third columns build on the simulation in the first column as follows. The monetary policy cycle generates a path for the DSR and, consequently, for the transition variable $F(z_t)$. At each point along this simulated path, we use the value of $F(z_t)$ implied by the cumulated monetary policy shocks up to that date to compute the IRF to a new one-standard-deviation monetary policy shock occurring at that point, following the approach described in equations 4 and 5.[15] The 1 percentage point tightening (loosening) produces a negative (positive) effect on output and inflation, reaching peaks in absolute values, respectively, of 3.1% (3.0%) and 2.5% (1.9%). The tightening (loosening) has negative (positive) effect on EDF of 0.15 percentage points (0.1 percentage points) and a negative (positive) effect on house prices of -2.8% (2.7%) at peak. DSR increases by 45 basis points under the tightening (and decreases by 50 basis points under the loosening). Overall, the tightening has stronger effects than loosening in absolute terms: this sign-dependent effect owes to the fact that over time monetary policy interventions become more impactful over a tightening cycle, as the DSR increases. This result echoes the finding in Tenreyro and Thwaites [2016] who report that contractionary monetary policy shocks tend to have a stronger effect in absolute terms than expansionary shocks. The second and the third column of Figure 5 show that over a loosening cycle, monetary policy gradually reduces its own effectiveness, whereas the opposite is true in the case of a tightening. The plots display the IRFs to a monetary policy shock that takes place two quarters and four quarters after the beginning of the corresponding monetary cycle. Two quarters after the beginning of the cycle, the differences in terms of DSR are still relatively contained, moving the transition variable from the initial level ($F(z_t) = 0.5$) to 0.58 (0.43) in the case of a tightening (loosening). However, after four quarters, the effects on the DSR are larger, implying a transition function value of 0.75 (0.25) in the case of a tightening (loosening). The differences in the effect of monetary policy become much larger. The estimates indicate that the responses of output and inflation to a monetary policy shock are stronger when the shock follows four quarters of tightening relative to four quarters of loosening, by approximately 22 basis points at peak. A contractionary monetary policy shock is also more impactful on the median EDF following a tightening cycle, relative to a loosening cycle.

[15] Section 6. considers alternative scenarios where the tightening takes place in expansionary/recessionary environments, implying that the short-term rate movement can also be the result of an endogenous reaction to other structural shocks hitting the economy. The implications for monetary policy effectiveness over the tightening cycle can materially change.

5.2 The size dependent effect

Figure 6 explores how the steepness of the monetary policy cycle can affect the effectiveness of subsequent monetary policy shocks. A steeper monetary policy tightening (loosening) is associated with a stronger change in monetary policy effectiveness. As in Section 5.1, the IRFs at the end of each cycle are computed following equation 4, with the value of $F(z_t)$ updating endogenously in response to the cumulated monetary policy shocks over the cycle, as in equation 5. The first row reports in red (blue) how the monetary policy rate evolves over the policy cycle. On the left column, the policy rate is increased (decreased) by 1 percentage point over four quarters. The second column reports the propagation of the monetary policy shock if in the same horizon the tightening (the loosening) is 4 times larger, reaching 4 percentage points at the end of the tightening (loosening). This steeper tightening (loosening) causes the DSR and the transition variable to move faster, with the transition values reaching $F(z_t) = 0.98$ ($F(z_t) = 0.01$). Under the steeper tightening, the contractionary effect on output and inflation is visibly larger than under the 1 percentage-point tightening; the opposite holds after the steeper loosening. The difference in the EDF response across cycle sizes is more muted, consistent with the lower sensitivity of expected default frequencies to the policy rate path.

6. Effectiveness of monetary policy over the business cycle

This section investigates how monetary policy effectiveness and the business cycle evolution influence each other. Since tightening and loosening cycles affect the financial exposure of the economy in future periods, this generates state dependence in the effectiveness of subsequent monetary policy. We first show that economic and financial shocks are amplified when they take place following a tightening cycle, whereas the opposite is true when the shocks follow a loosening period. Next, we show that over a tightening cycle, monetary policy effectiveness increases less if the tightening happens during an expansion, whereas if the tightening takes place during a downturn the effect of monetary policy is even stronger, as debt servicing pressures intensify.

6.1 Amplification of business-cycle shocks following different monetary policy cycles

Figure 7 shows the estimated IRFs of macroeconomic and financial variables to a negative housing price shock (left hand side column) and to a negative GDP shock (right hand side column). For each type of shock, we simulate the same one-standard deviation shock in three different scenarios: when the economy is at its median state ($F(z_t) = 0.5$, yellow line), after one year of 1 percentage-point tightening ($F(z_t) = 0.75$, red line), and after one year of a 1 percentage-point loosening ($F(z_t) = 0.25$, blue line). The values of $F(z_t)$ in the tightening and loosening scenarios correspond to those obtained after one year of the respective monetary policy cycles simulated in Section 5.1, and are computed following equation 4.

The housing price shock can be interpreted as an exogenous variation in housing preferences, decreasing housing prices on impact, and having an impact on macroeconomic variables and the policy rate in subsequent periods. The shock decreases house prices by 40 basis points in the first part of the projection across the three scenarios considered. However, the effects of the housing price shock are substantially amplified following a tightening period, whereas the opposite is true following a loosening period. In particular, the effect on output is four times larger when the shock takes place after a tightening cycle than when it takes place after a loosening cycle. In turn, after two years inflation decreases by 45 basis points at peak when the shock follows a tightening cycle, and by 16 basis points when the shock follows a loosening cycle. Consistent with the stronger reactions of output and inflation, the policy rate falls by more when the shock follows a tightening period (-0.35%, peak effect) than when it follows a loosening period (-0.06%, peak effect). The shock also triggers a stronger increase on EDF and a sharper decrease in DSR when it follows a tightening period; the latter effect reflects the stronger reaction of the short-term rate when the house price shock follows a tightening cycle.

The recessionary output shock can be interpreted as an exogenous decrease in aggregate demand, which reduces activity and inflation. Within the first quarter, the shock triggers a reduction in the short-term rate to offset the fall in demand, an increase in financial stability risks through higher EDF, and a reduction in house prices. In the first part of the projection, when the demand shock takes place after a tightening period, the shock has a much larger impact on output than when it takes place after a loosening period, reaching peak values of -0.4% and -0.2%, respectively at the peak effect. The reaction of inflation is negative in both cases, but fairly similar across the three scenarios. The EDFs respond similarly across the different scenarios: they increase in the first part of the projection (+3bp), but fall again, as output recovers. House prices decrease slightly in the first part of the projection and increase in the second part of the projection, partly in response to lower policy rates.[16] DSR increases on impact, given the reduction in output. The overall increase of the DSR is higher when the demand shock follows

[16] In New Keynesian models featuring housing in the utility function, a negative demand shock can induce an increase in house prices. Activity and the price of consumption goods decrease, while house price increase.

a loosening period (reaching a peak effect of +0.7pp), whereas the increase is close to zero if the shock takes place after a tightening period. The difference reflects the reaction of the policy rate, which falls more forcefully when the demand shock takes place following a tightening cycle, consistent with the stronger economic downturn.

6.2 Interactions between the monetary tightenings and business cycles

We next explore how business cycle conditions affect the marginal effectiveness of monetary policy over a monetary cycle. As in Section 5.1, the dynamics under each scenario are obtained following equations 4 and 5, with the transition variable $F(z_t)$ updating endogenously in response to the combination of shocks hitting the economy in each scenario. Figure 8 displays the IRFs of macroeconomic and financial variables to a 1 percentage-point monetary policy tightening taking place over the first year of the projection, under three different scenarios: i) neutral business cycle conditions, in which any observed tightening is accounted for by monetary policy shocks; ii) recession, where output is conditioned to decrease by 2% in the first year of the projection; iii) expansion, where output is conditioned to increase by 2% in the first year. In the recessionary and in the expansionary scenarios, a combination of output and monetary policy shocks hits the economy during the first four quarters, jointly generating a tightening and a recession (or expansion). All simulations start from a median financial exposure level, that is, $F(z_t) = 0.5$. The first column displays the dynamics of the endogenous variables of the model. In the expansionary case (yellow lines), part of the monetary policy tightening is accounted for by the endogenous response to the expansionary output shocks. Output and inflation remain positive over the projection. House price responses fluctuate around zero, whereas EDF decrease in the first part of the projection to -0.22pp and then increase in the second part of the projection, in line with the deceleration of output growth. DSRs slightly decreases, owing to the fact that the policy tightening happens during an expansionary phase, and the increase of the DSR numerator (through the short-term interest rate) is more than offset by the increase in the denominator (through the output expansion). As a result, despite the monetary tightening, the state of the economy decreases ($F(z_t) = 0.30$ at the end of the tightening). When the tightening happens in a recessionary environment (red lines), activity deteriorates materially over time (reaching a peak of -5% at the end of the second year). In line with this, inflation and house prices also fall materially, respectively reaching -5.4 and -3.6 percentage points at their peaks. Given the increase in policy rates and the output contraction, the DSR increases by 64 basis points, substantially increasing the transition variable of the economy to $F(z_t) = 0.88$. In the neutral-cycle simulation (blue lines), the effects are somewhere in between the recessionary and expansionary extremes.

The second column of Figure 8, displays the IRFs to a one standard deviation iid monetary policy shock under the three scenarios discussed above. In line with the evolution of the state variables under the recessionary (expansionary) scenario, the recession (expansion) amplifies (reduces) the potency of the monetary policy shock, when the monetary policy shock takes place after a tightening cycle. The third column shows the differences of the IRFs of the iid one standard-deviation monetary policy shock with the median impulse response ($F(z_t) = 0.5$). In the expansionary scenario, the effectiveness of monetary policy remains stable over the tightening period. The amplification effect generated by the tightening is muted by the economic expansion. In the tightening baseline scenario (blue lines) and in the recessionary scenario (red lines), the effectiveness of monetary policy is amplified: the response on output at its peak is, correspondingly, -0.10 and -0.18 percentage points. Inflation decreases more when the monetary policy shock takes place under neutral business cycle conditions (-0.17 percentage points at peak) and when the policy shock takes place in a recession (-0.23 percentage points). The monetary policy shock implies also a stronger increase in financial stability risk, through higher EDFs. The effect is slightly higher when the tightening happens in the recessionary environment. During the expansion, the increase in output offsets the impact of the monetary policy shock on financial exposure.

These findings speak to the debate over the impact of tightenings during demand-driven versus supply-driven inflationary environments. Our recessionary scenario captures a situation where tightening coincides with weak output, leading to sharper deterioration in DSRs and stronger monetary policy effectiveness. Conversely, our expansionary scenario is more consistent with a demand-driven environment, where the output expansion offsets the impact on financial exposure and monetary policy effectiveness remains broadly stable.

7. Conclusions

Using a flexible nonlinear empirical model, we show that monetary policy effects are amplified when financial exposure levels, gauged by debt-servicing ratios, are elevated. Since monetary policy itself can affect the level of financial exposure over time, it can affect its own effectiveness over a monetary policy cycle. To assess these effects, the model allows the state variable of the nonlinear model to be endogenous. The estimates indicate that monetary policy tightenings become more potent over time, while monetary policy loosenings lose effectiveness over time. Size and pace matter: larger and faster tightenings make subsequent monetary policy changes stronger.

We also show that monetary policy can affect the sensitivity of the economy to other economic and financial shocks, including demand and housing price shocks. Following a monetary tightening period in a neutral or recessionary environment, debt-servicing ratios increase, and the economy becomes more sensitive to subsequent demand and house price shocks, while the opposite is true following a monetary policy loosening period.

Finally, we show that the effectiveness of monetary policy depends on and interacts with business cycle conditions. If a monetary policy tightening takes place during an expansion, financial exposure is broadly unaffected, and the effectiveness of monetary policy remains stable. If instead a monetary policy tightening takes place during a downturn, financial exposure is more elevated, making monetary policy more impactful.

As a by-product, the analysis sheds some light on the relation between monetary policy and financial stability. When financial exposure in the economy is elevated, the marginal effect of contractionary monetary policy shocks on banks' probability of default increases, particularly so if the tightening happens during recessions. By affecting financial exposure, monetary policy can also alter the sensitivity of the economy to subsequent shocks, which has further implications for financial stability. These links deserve further study.

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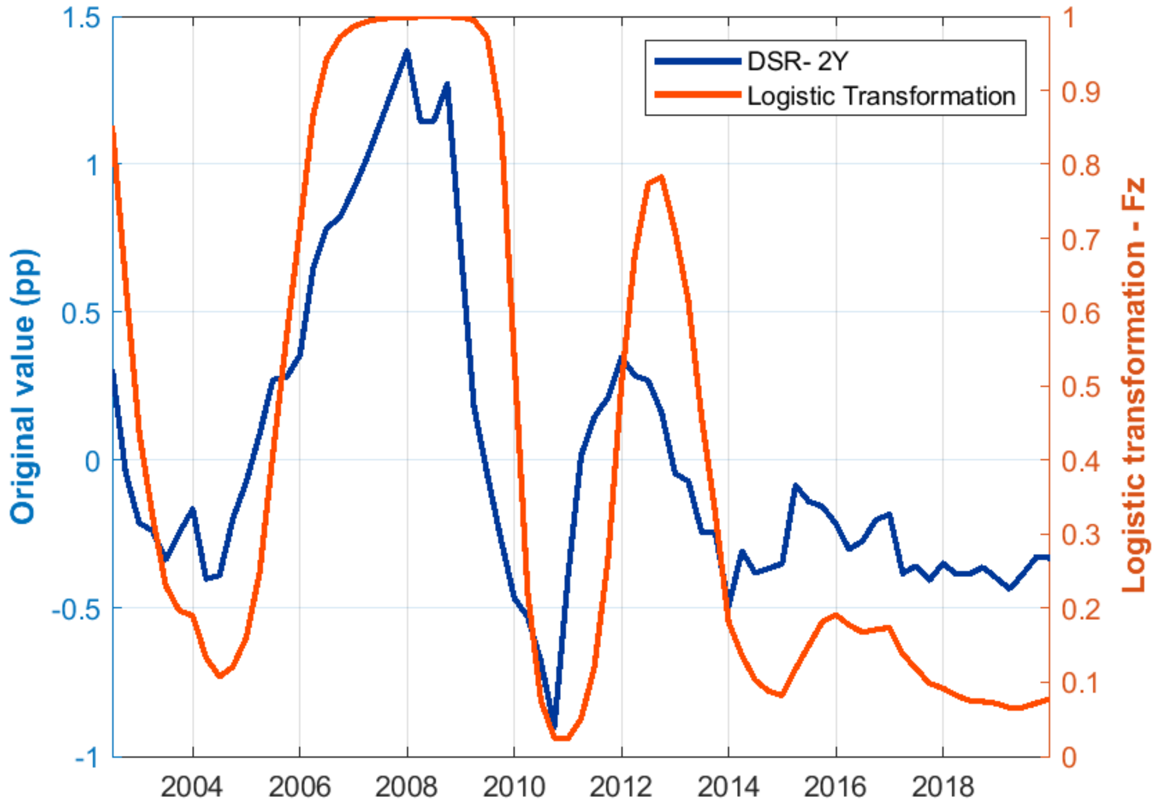
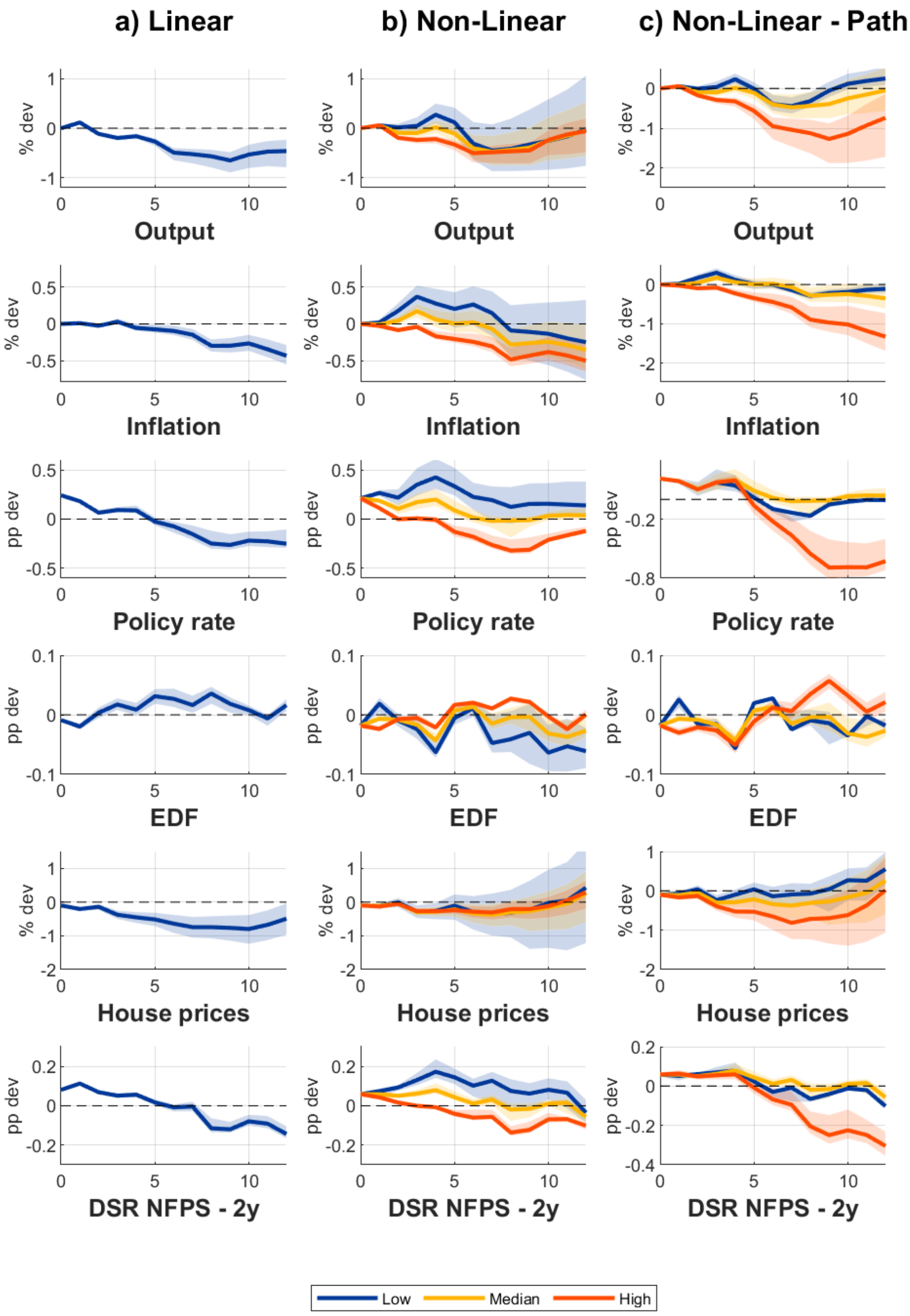
Figure 1: Debt service ratio (two-year difference) and logistic transformation



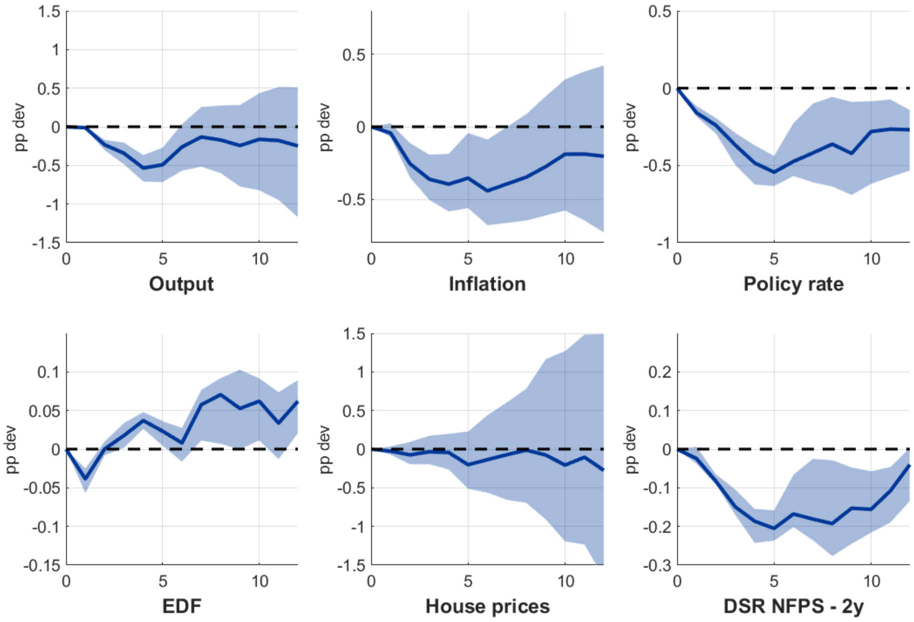
Notes: The figure plots the debt service ratio of the non-financial private sector in two-year difference (blue line, left-hand axis) and its logistic transformation (red line, right-hand axis).

Figure 2: Monetary policy shock: Linear and nonlinear case



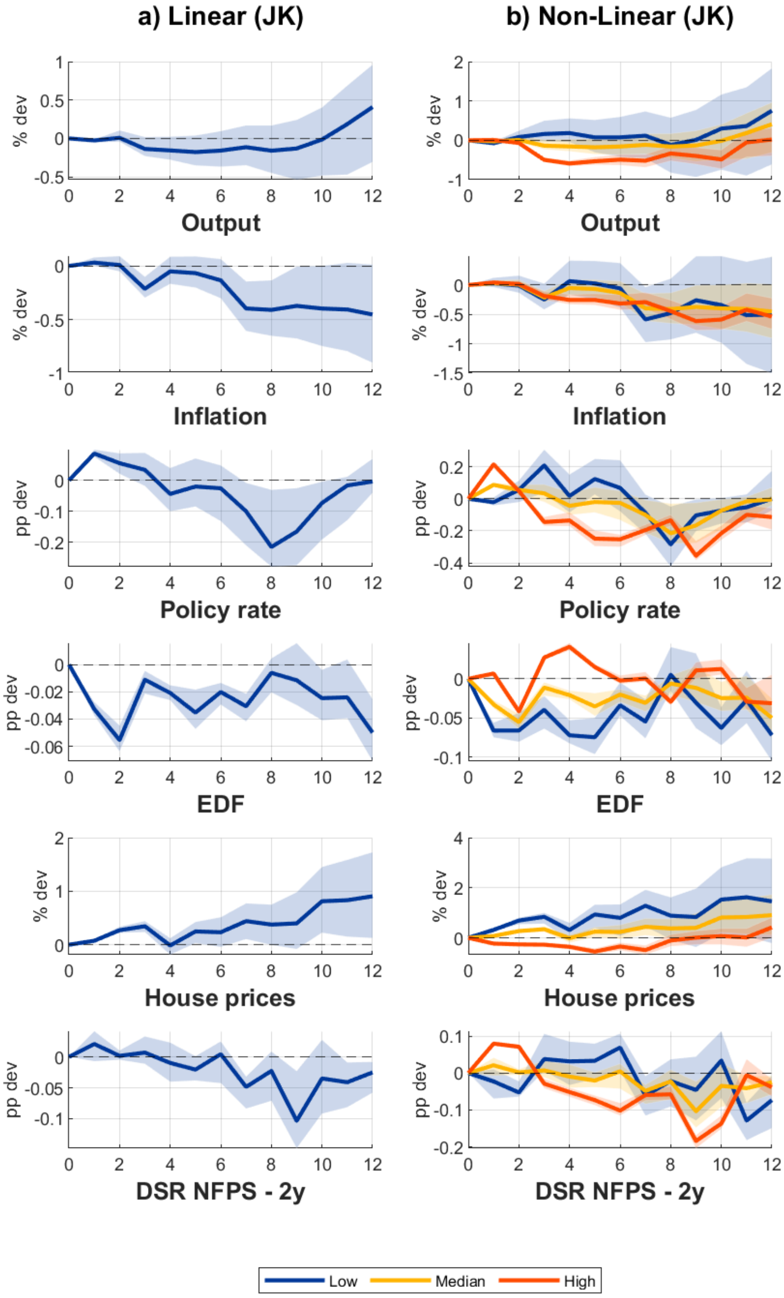
Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The first column shows responses to an i.i.d. shock in the linear specification. The second column reports responses in the nonlinear specification to an i.i.d. shock under minimum (blue line), median (yellow line), and maximum financial exposure (red line). The third column shows responses conditional on the policy rate exhibiting the same path across the three exposure levels over the first year of the projection. Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Figure 3: Monetary policy shock: Statistical significance of state-dependent amplification



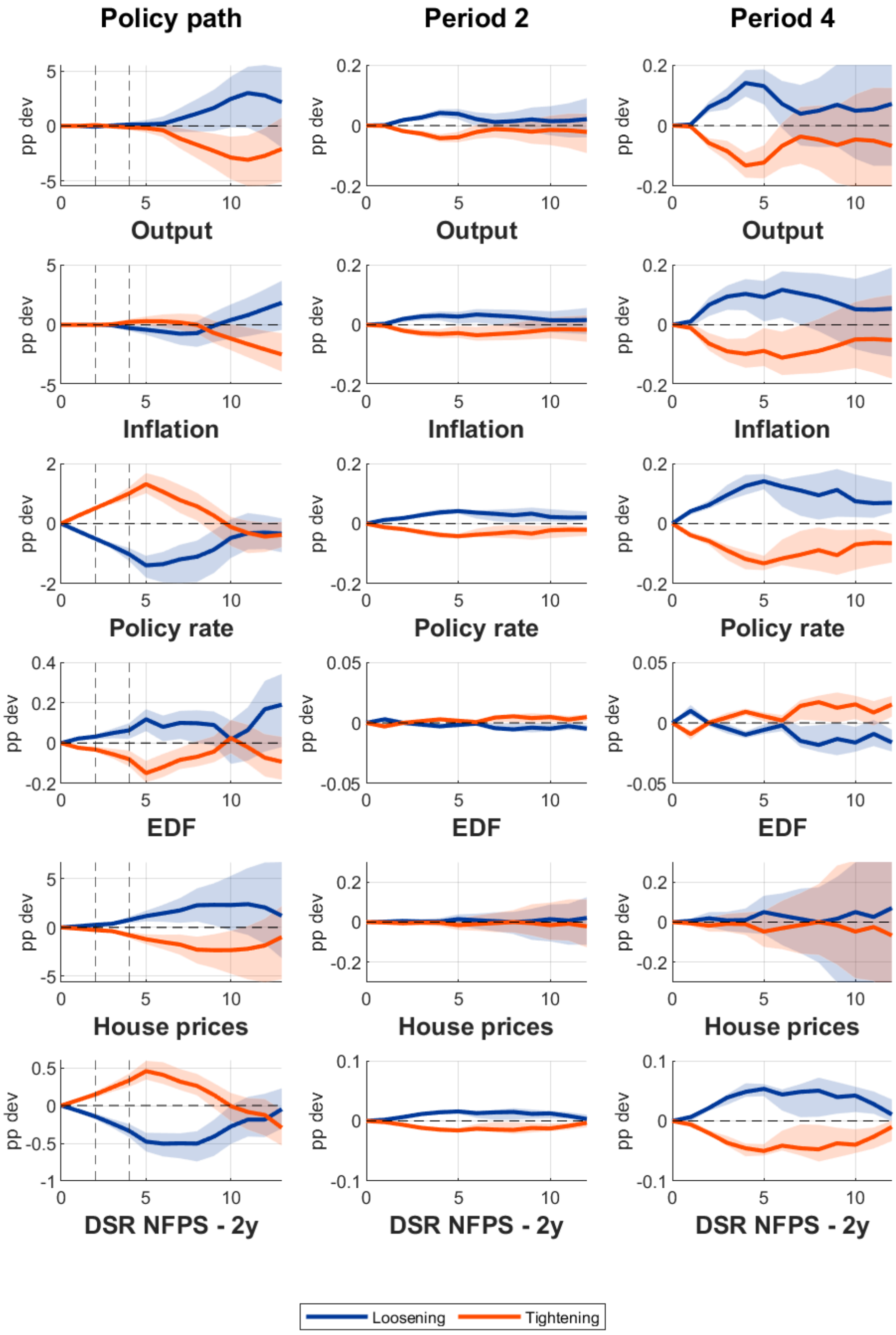
Notes: This figure reports the difference between impulse responses in the high-exposure state ($F(z_t) = 1$) and the low-exposure state ($F(z_t) = 0$), with 67% bootstrap confidence bands constructed from the joint distribution of the difference within each bootstrap draw. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Figure 4: Monetary policy shock identified via external instrument: Linear and nonlinear case



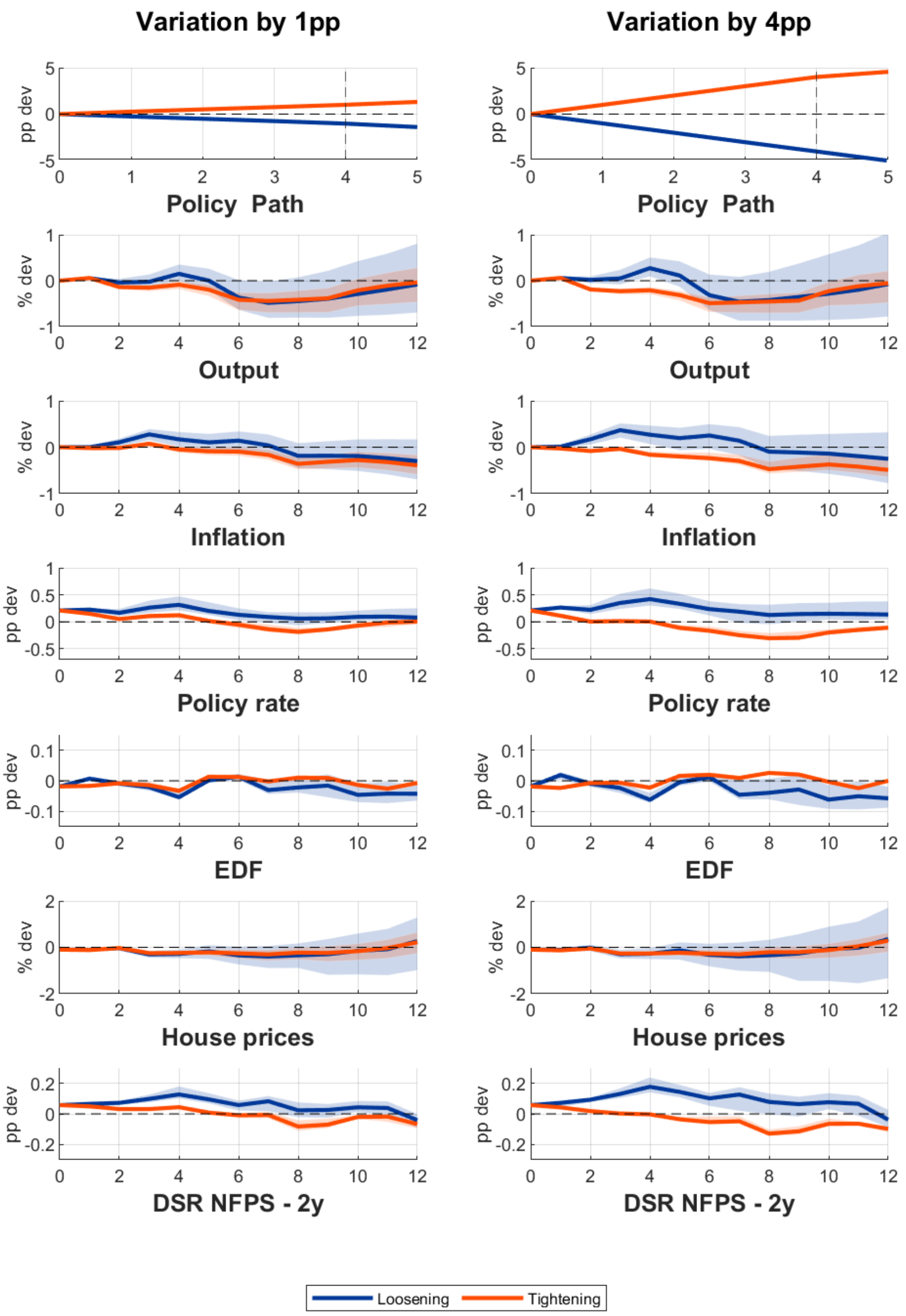
Notes: State-dependent difference in impulse responses. Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The monetary policy shock is identified in Jarociński and Karadi [2020]. The shock is normalised to one standard deviation. The first column shows responses to an i.i.d. shock in the linear specification. The second column reports responses in the nonlinear specification to an i.i.d. shock under minimum (blue line), median (yellow line), and maximum financial exposure (red line). Shaded areas denote 67% confidence intervals constructed via block bootstrap. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Figure 5: Change in effectiveness of monetary policy over tightening and loosening periods



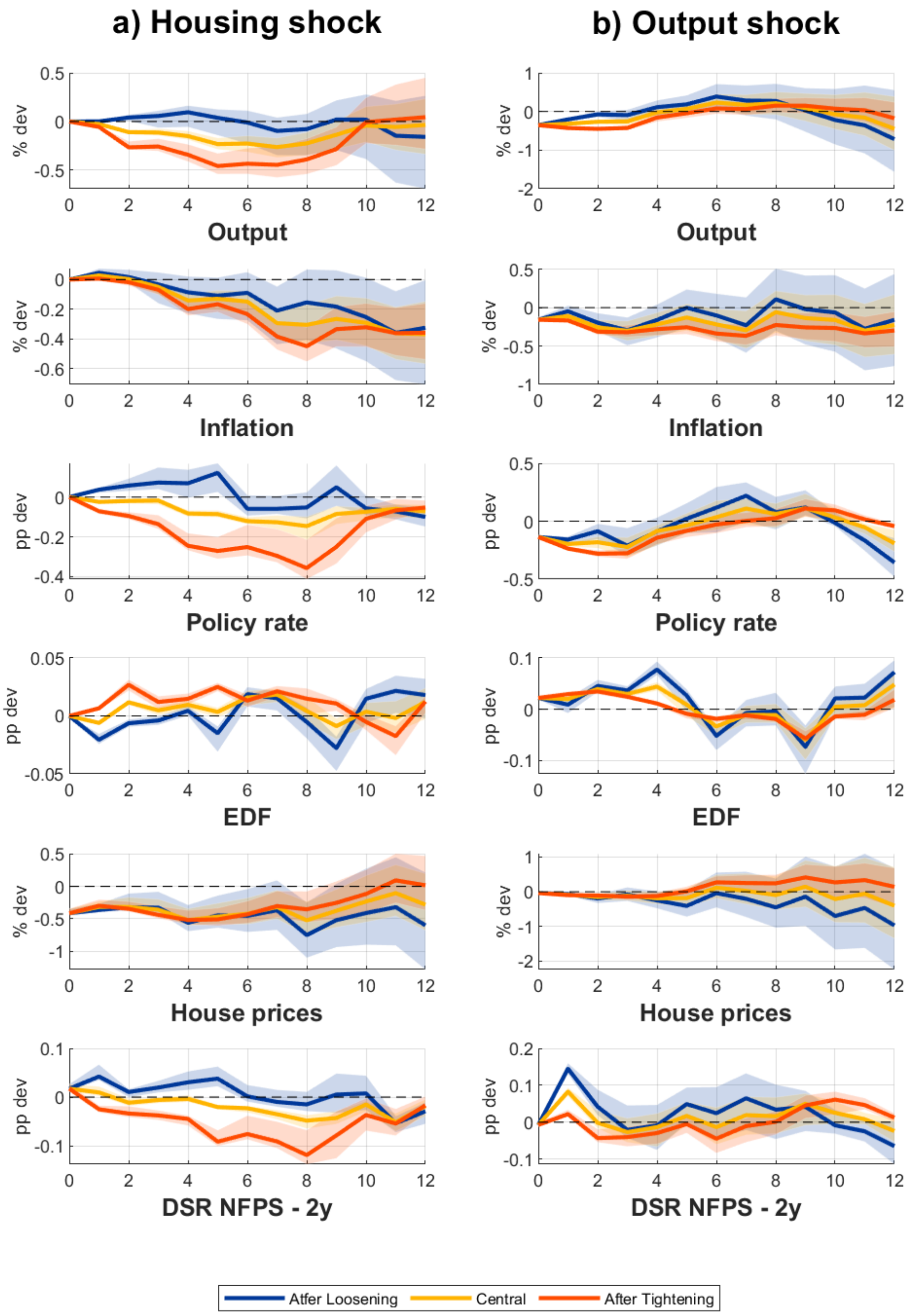
Notes: The first column shows the responses of the economy conditional on a one–percentage-point tightening (red line) and loosening (blue line) of the policy rate over one year. The second (third) column reports difference between the responses of a one–standard-deviation i.i.d. shock occurring two (four) quarters after the start of the tightening (red line) or loosening (blue line) episode and the median impulse response ($F(z_t) = 0.5$). Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Figure 6: Effectiveness of monetary policy over tightening and loosening cycles featuring different steepness



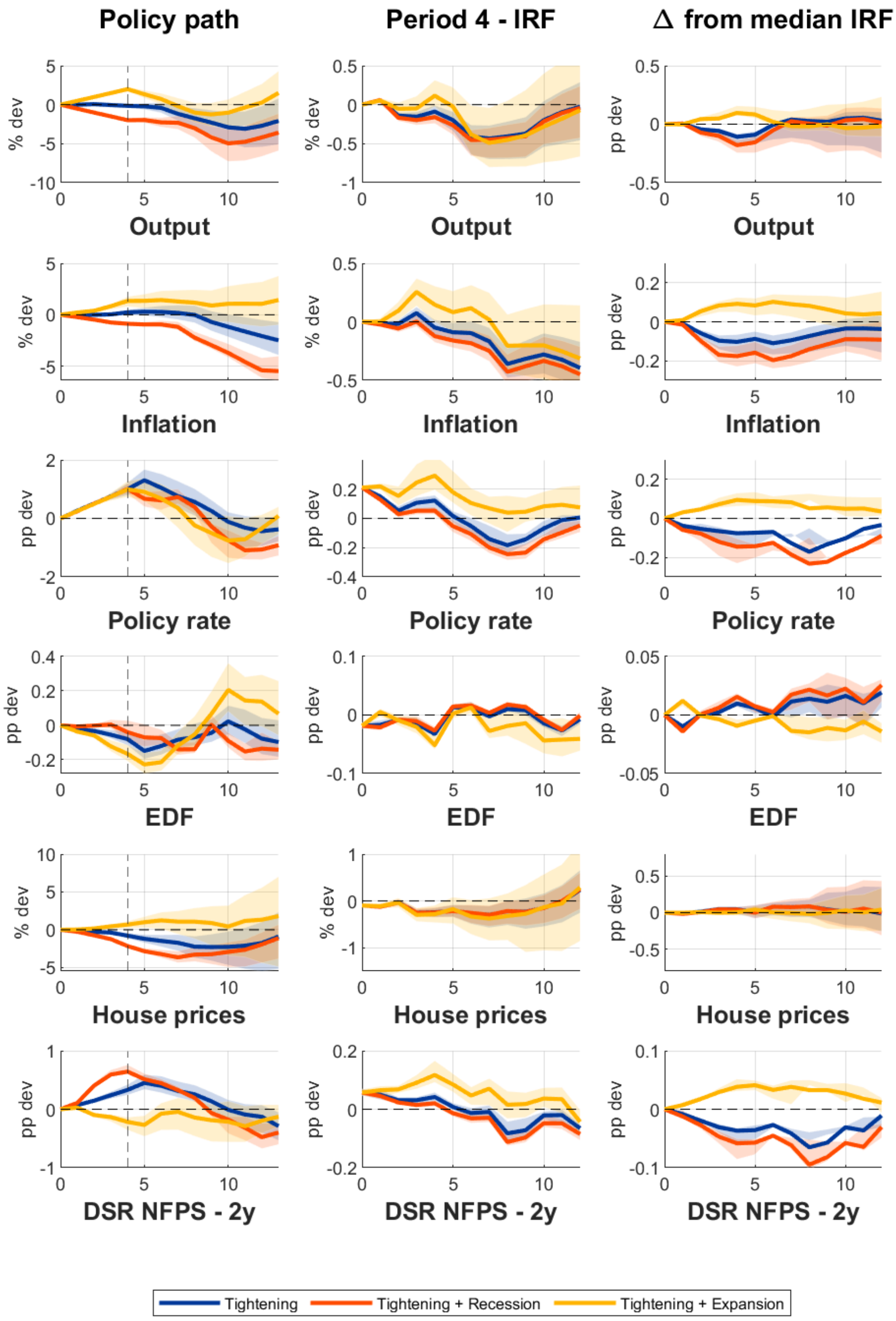
Notes: The first column shows responses to a one–standard-deviation i.i.d. shock occurring at the end of a four–quarter, one–percentage-point tightening (red line) or loosening (blue line) of the policy rate. The second column shows responses to a one–standard-deviation i.i.d. shock occurring at the end of a four–quarter, four–percentage-point tightening (red line) or loosening (blue line). Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Figure 7: Propagation of Housing shock and Output shock under different monetary cycle phases.



Notes: This figure reports impulse response functions to a one–standard-deviation housing shock (first column) and a one–standard-deviation output shock (second column). Responses are shown after one year of tightening (red lines), one year of loosening (blue lines), and under the median financial exposure case ($F(z_t) = 0.5$, yellow line). Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Figure 8: Effectiveness of monetary policy over tightening under different phases of the business cycle



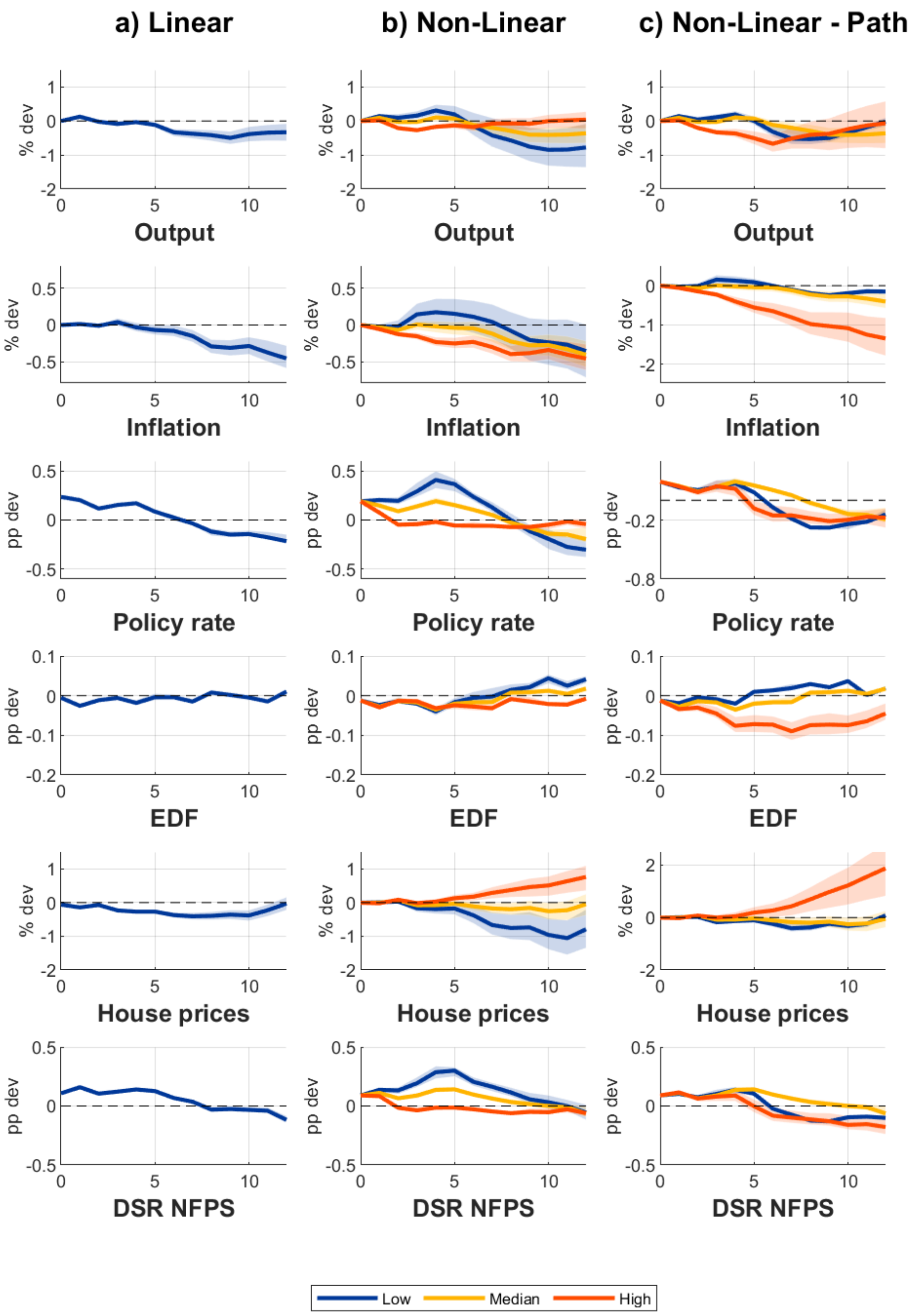
Notes: This figure reports responses to a one–percentage-point tightening of the policy rate over one year under a recession (red line), an expansion (yellow line), and a neutral economic environment (blue line). The first column shows responses of the economy. The second column shows responses to a one–standard-deviation i.i.d. shock occurring four quarters after the start of the projection under the three scenarios. The third column shows the differences between the impulse responses under each scenario and the impulse response under the median financial exposure case ($F(z_t) = 0.5$). Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Online Appendix

A Robustness: DSR in levels

We perform the estimation using the debt-servicing ratio in levels as the state variable, instead of the two-year difference used in the baseline. As shown in Figure A.1, the results are qualitatively similar and the state-dependent effects documented in the main text are confirmed, with the exception of EDF and house prices. In particular, the amplification under high financial exposure is most clearly visible when the policy rate path is conditioned to follow the same trajectory across the three states during the first year of the projection (third column), which removes the confounding effect of the differential endogenous monetary policy response across exposure levels.

Figure A.1: Monetary policy shock: Linear and nonlinear case - Specification with DSR in levels

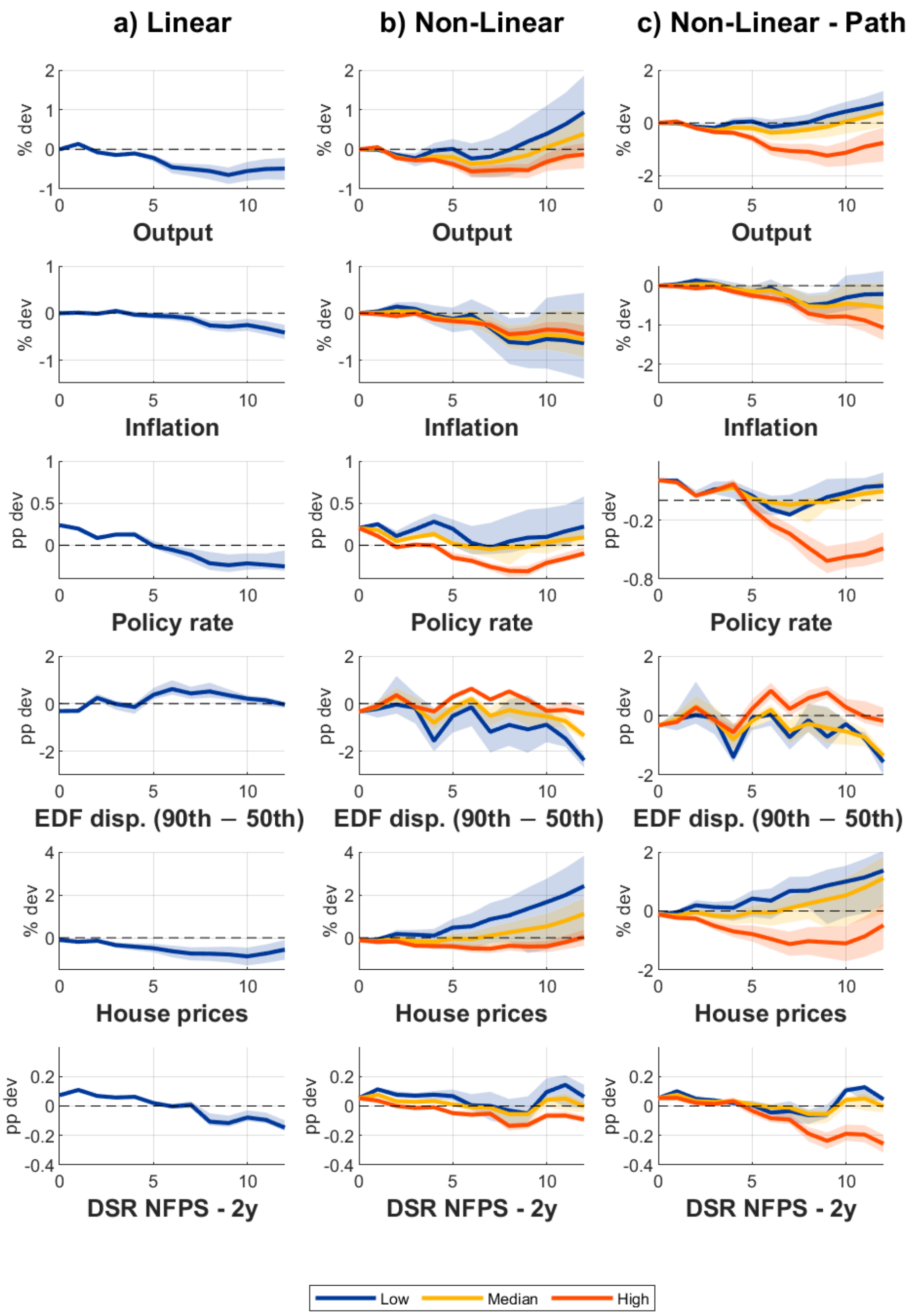


Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The first column shows responses to an i.i.d. shock in the linear specification. The second column shows responses to an i.i.d. shock in the nonlinear specification under minimum (blue line), median (yellow line), and maximum financial exposure (red line). The third column shows responses conditional on the policy rate following the same path across the three financial exposure levels during the first year of the projection. Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

B Robustness: Specification with EDF dispersion

In this section, we replace the median EDF with the difference between the 90th percentile EDF and the median EDF to assess how monetary policy effectiveness varies with EDF dispersion across the banking system. The results are qualitatively very similar to those in the baseline estimation. In the case of a tightening, EDF dispersion increases only in the high-financial exposure state (Figure B.2).

Figure B.2: Monetary policy shock: Linear and nonlinear case - Specification with EDF dispersion

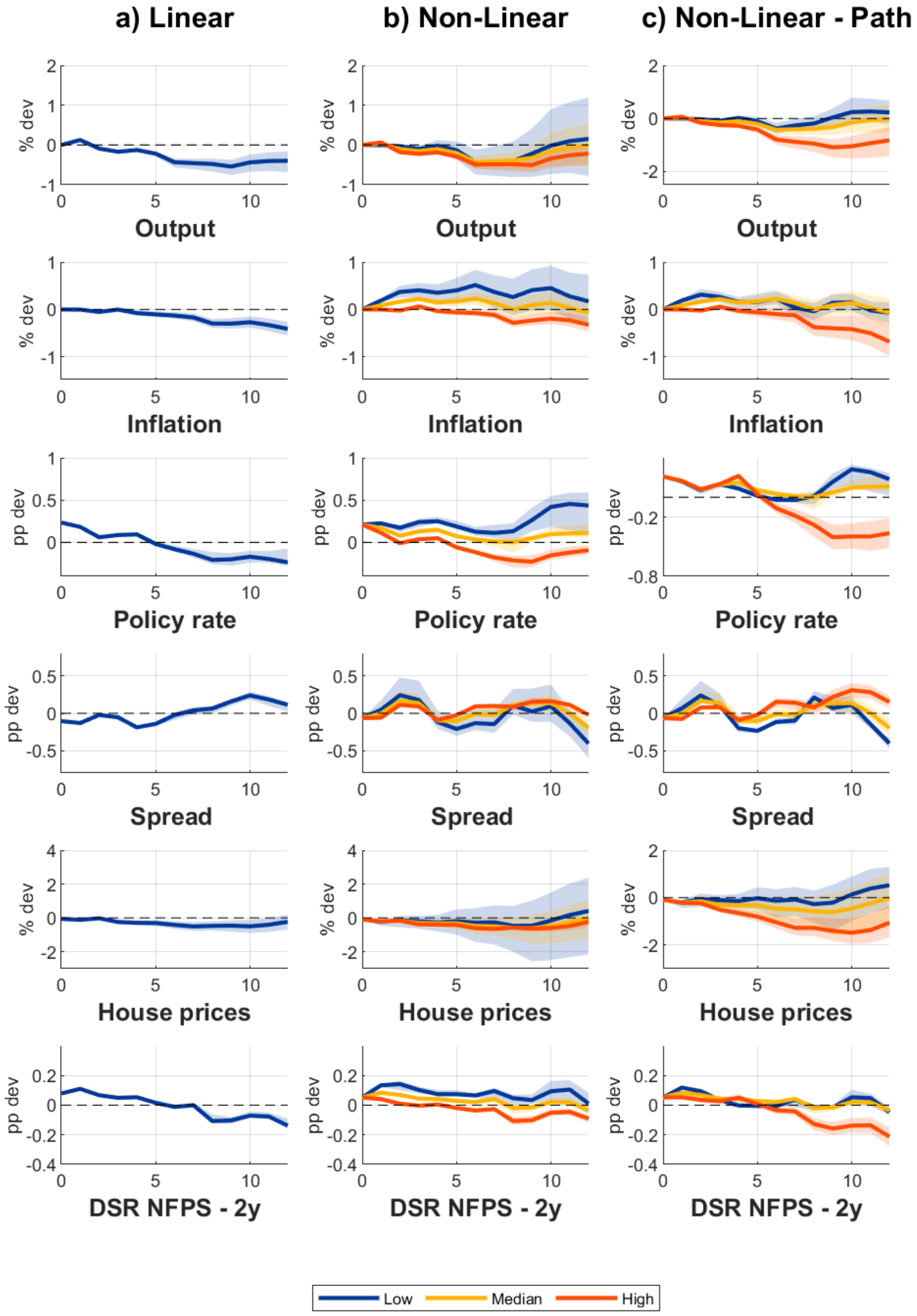


Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The first column shows responses to an i.i.d. shock in the linear specification. The second column shows responses to an i.i.d. shock in the nonlinear specification under minimum (blue line), median (yellow line), and maximum financial exposure (red line). The third column shows responses conditional on the policy rate following the same path across the three financial exposure levels during the first year of the projection. Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

C Robustness: Specification including Spreads

We perform the estimation using the spread instead of the EDF. As shown in Figure C.3, the results are qualitatively similar, and the state-dependent effects highlighted in the paper are confirmed.

Figure C.3: Monetary policy shock: Linear and nonlinear case - Specification including Spread

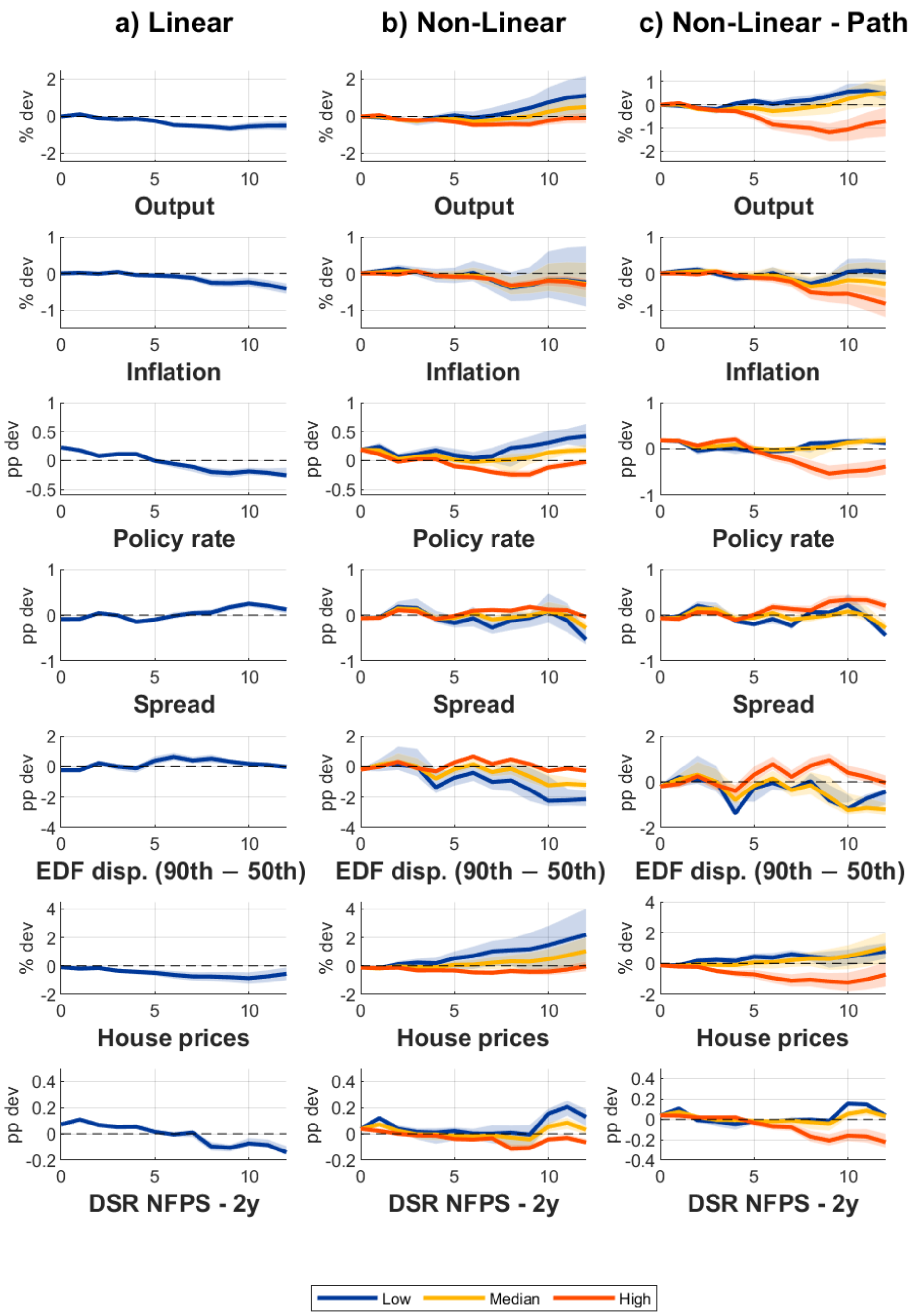


Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The first column shows responses to an i.i.d. shock in the linear specification. The second column shows responses to an i.i.d. shock in the nonlinear specification under minimum (blue line), median (yellow line), and maximum financial exposure (red line). The third column shows responses conditional on the policy rate following the same path across the three financial exposure levels during the first year of the projection. Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

D Robustness: Specification including Spread and EDF dispersion

We run the estimation by using spread and EDF dispersion jointly. As shown in Figure D.4 results are qualitatively similar and the state dependent effects highlighted in the paper are confirmed.

Figure D.4: Monetary policy shock: Linear and nonlinear case - Specification including Spread and EDF dispersion

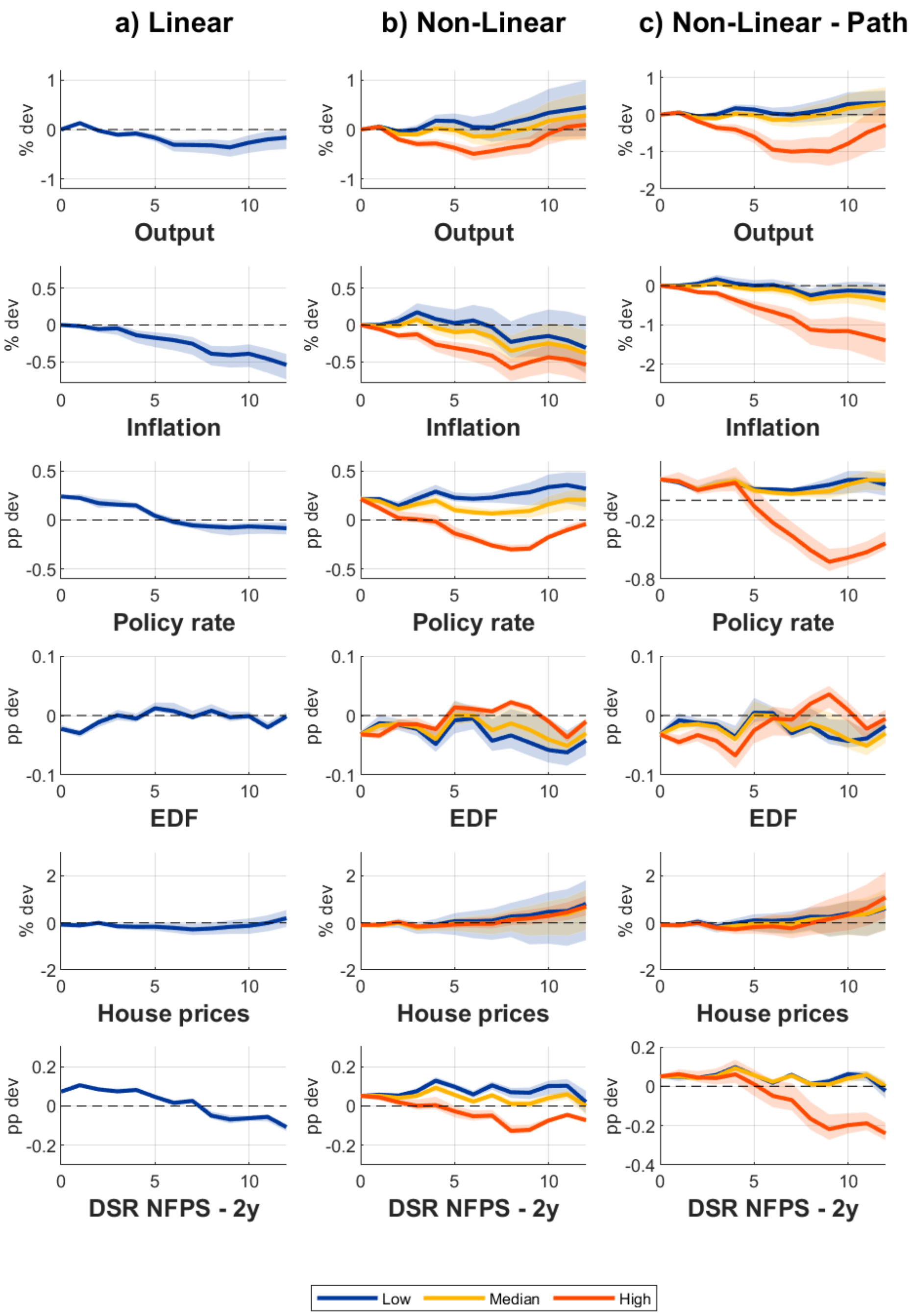


Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The first column shows responses to an i.i.d. shock in the linear specification. The second column shows responses to an i.i.d. shock in the nonlinear specification under minimum (blue line), median (yellow line), and maximum financial exposure (red line). The third column shows responses conditional on the policy rate following the same path across the three financial exposure levels during the first year of the projection. Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

E Robustness: Sample including Covid period

We perform the estimation over a longer sample (2001Q1–2023Q4), thereby including the Covid episode. As shown in Figure E.5, the results are similar, and the state-dependent effects highlighted in the paper are confirmed. Covid quarters (2020Q1–2020Q3) are absorbed via an additive dummy variable. The extended sample estimation uses ridge regression with regularisation parameter $\lambda = 10^{-6}$ to ensure numerical stability. This regularisation is applied exclusively in this appendix and is not used in the baseline estimation. It is required because the Covid dummy variable — which takes value one for 2020Q1–Q3 and zero otherwise — has very few non-zero entries relative to the block bootstrap sample size, creating near-collinearity in some bootstrap draws.

Figure E.5: Monetary policy shock: Linear and nonlinear case - Sample including Covid period



Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The first column shows responses to an i.i.d. shock in the linear specification. The second column shows responses to an i.i.d. shock in the nonlinear specification under minimum (blue line), median (yellow line), and maximum financial exposure (red line). The third column shows responses conditional on the policy rate following the same path across the three financial exposure levels during the first year of the projection. Shaded areas denote 67% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

F Robustness: Estimation parameters of the transition function

Table F.1 examines the sensitivity of the baseline results to the choice of the logistic smoothing parameter θ and threshold c. For each combination in a grid of $\theta \in \{1, 2, 3, 5, 10\}$ and $c \in \{p25, p50, p75\}$ of z_t, we re-estimate the model and report the difference $\text{IRF}(F = 1) - \text{IRF}(F = 0)$ for output and inflation at horizon $h = 8$. A negative value indicates that the contractionary effect of a monetary policy shock is larger under high financial exposure than under low financial exposure, consistent with the state-dependent amplification documented in the main text.

The results are robust across 13 of the 15 combinations for output, and across all 15 combinations for inflation. The two exceptions arise at $c = p25$ combined with $\theta \in \{5, 10\}$, parameterisations that assign more than 80% of the sample to the high-exposure regime, leaving the low-exposure regime with insufficient effective observations for stable estimation. The baseline specification ($\theta = 3$, $c = p50$) lies in the interior of the robust region.

Table F.1: Sensitivity of state-dependent amplification to θ and c

	Output			*Inflation*		
θ	$c = p25$	$c = p50$	$c = p75$	$c = p25$	$c = p50$	$c = p75$
1	−0.775	−0.691	−0.414	−0.731	−0.658	−0.533
2	−0.457	−0.432	−0.322	−0.562	−0.467	−0.403
3	−0.109	**−0.184**	−0.311	−0.428	**−0.351**	−0.354
5	+0.148	−0.078	−0.290	−0.469	−0.284	−0.338
10	+0.167	−0.038	−0.257	−0.821	−0.313	−0.343

Notes: Each cell reports $\text{IRF}(F = 1) - \text{IRF}(F = 0)$ for a one–standard-deviation monetary policy shock at horizon $h = 8$, under alternative values of the logistic smoothing parameter θ and threshold c (expressed as percentiles of z_t). Negative values indicate larger contractionary effects under high financial exposure. Bold entries denote the baseline specification ($\theta = 3$, $c = p50$).

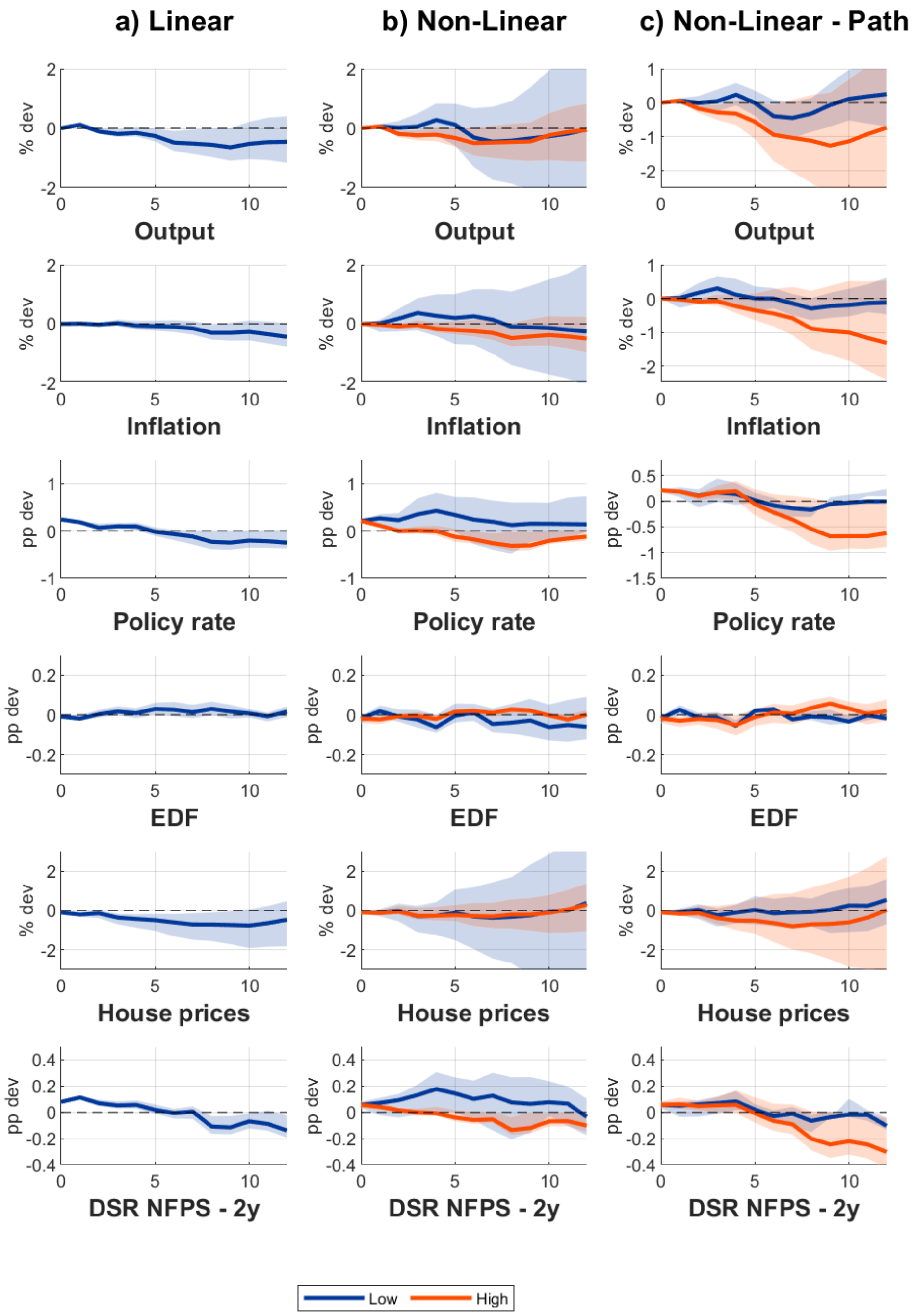
G Robustness: 90% Confidence intervals

This appendix replicates the main figures using 90% confidence bands instead of the 67% bands reported in the main text. For clarity, we show only the high- and low-exposure cases, omitting the median.

Figure G.6 replicates Figure 2 using 90% confidence bands instead of the 67% bands reported in the main text, showing the high- and low-exposure cases. The state-dependent differences in impulse responses remain statistically distinguishable at the 90% level for output, inflation, and house prices, both in the case of a single iid shock (panel b) and along the simulated policy path (panel c).

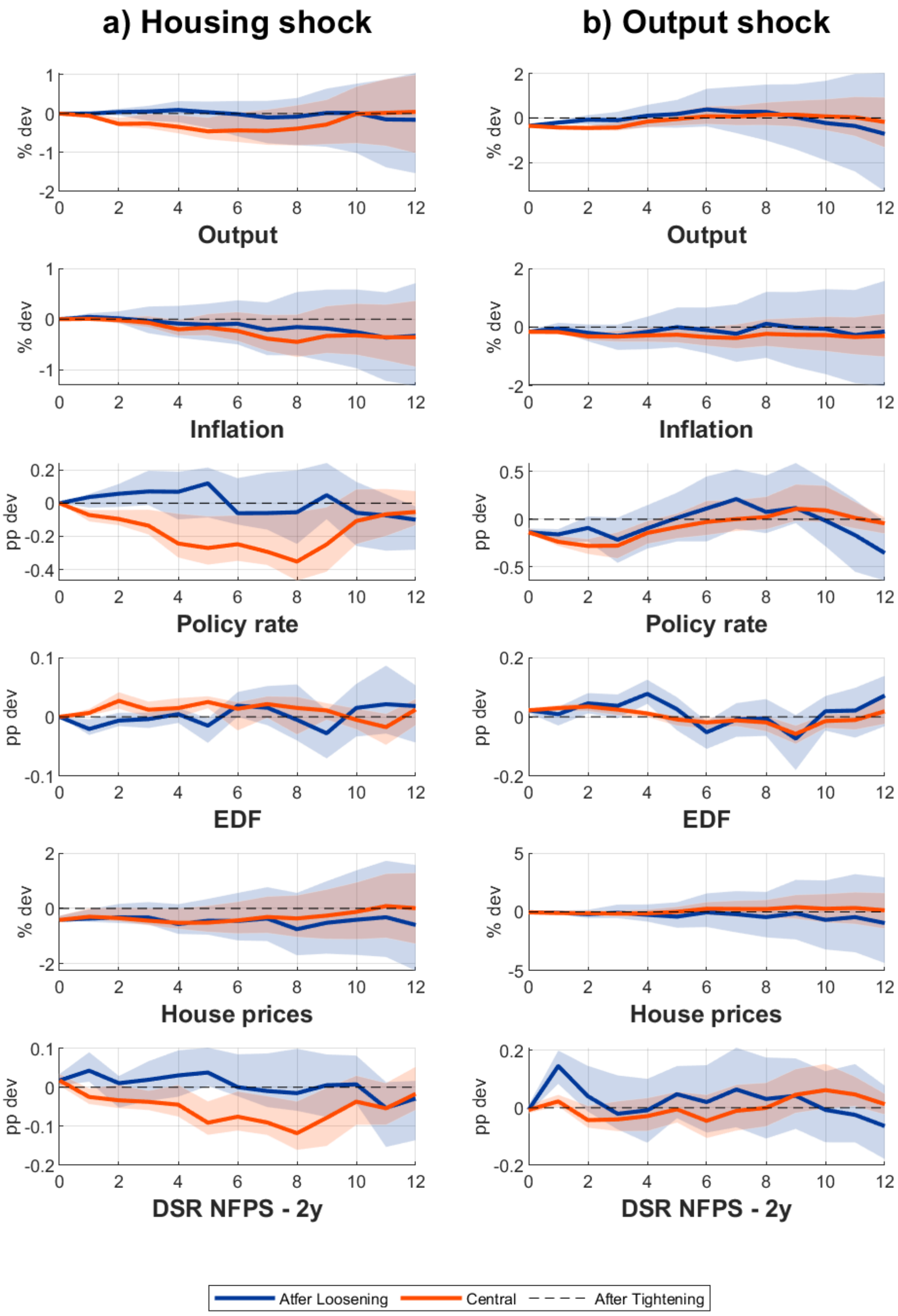
Figure G.7 replicates Figure 7, showing the propagation of housing and output shocks under different monetary cycle phases. The amplification of both shocks following a tightening cycle relative to a loosening cycle remains distinguishable at the 90% level for output and inflation, supporting the robustness of the main results.

Figure G.6: Monetary policy shock: Linear and nonlinear case — 90% confidence intervals



Notes: This figure reports impulse response functions to a one–standard-deviation monetary policy shock. The first column shows responses to an i.i.d. shock in the linear specification. The second column shows responses to an i.i.d. shock in the nonlinear specification under minimum (blue line) and maximum financial exposure (red line). The third column shows responses conditional on the policy rate following the same path across the three financial exposure levels during the first year of the projection. Shaded areas denote 90% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

Figure G.7: Propagation of Housing shock and Output shock under different monetary cycle phases — 90% confidence intervals



Notes: This figure reports impulse response functions to a one–standard-deviation housing shock (first column) and a one–standard-deviation output shock (second column). Responses are shown after one year of tightening (red lines) and one year of loosening (blue lines). Shaded areas denote 90% confidence intervals. Responses of output, inflation, and house prices are reported in cumulative terms, while responses of the remaining variables are shown in levels.

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