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Macroeconomic reversal rate in a low interest rate environment

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Abstract

This paper investigates how the monetary policy transmission channels change once the economy is in a low interest rate environment. We estimate a nonlinear model for the euro area and its five largest countries over the period 1999q2-2019q1 and allow for the effects of monetary policy shocks to be state dependent. Using smooth transition local projections, we examine the impulse responses of investment, savings, consumption, and the output gap to an expansionary monetary policy shock under normal and low interest rate regimes. We find evidence for a macroeconomic reversal rate related to the substitution effects becoming weaker relative to the income effects in a low interest rate regime. In this regime the effects of monetary policy shocks are either less powerful or reverse sign compared with a normal rate regime.

Keywords: reversal rate; monetary policy; low interest rate environment

JEL-Codes: E21, E22, E43, E52

Non-technical summary

An extended period of low interest rates may change the transmission of monetary policy to various components of aggregate demand. The decade following the Global Financial Crisis (GFC) has been marked by historically low interest rates and this phenomenon is expected to persist. It is therefore crucial to know whether the sensitivity of the economy to policy rate changes is different in a low - compared to a normal - interest rate environment. A prolonged period of low interest rates may cause higher savings of firms and households due to negative income effects of low interest rates. If these negative income effects dominate substitution effects, expansionary monetary policy may have a contractionary impact on the economy. At that juncture monetary policy hits the macroeconomic reversal rate, defined as the interest rate level at which further loosening of monetary policy becomes counter-productive in stimulating aggregate demand.

This paper examines nonlinearities in the monetary policy transmission mechanism by investigating whether the effects of monetary policy shocks change once the economy is in a low interest rate regime. For this purpose, we estimate a smooth transition local projections model for the euro area and its five largest countries and analyse whether the monetary policy transmission channels are regime dependent. Specifically, we test whether the impulse responses of the output gap and aggregate demand components to monetary policy shocks are different under two distinct regimes: a normal and low interest rate regime.

We expect the link between aggregate demand and monetary policy to be state-dependent since a prolonged period of low interest rates has implications for several channels of monetary policy transmission. First, the low-for-long interest rate environment affects consumption and savings patterns through the redistributive channel and the trade-off between substitution, income, and wealth effects. Second, it affects investments in capital goods due to diminishing returns on those assets as well as changes in the relative returns on financial assets.

Our results show that the monetary policy transmission changes in a persistently low interest rate environment, as indicated by different responses of macroeconomic aggregates to monetary policy shocks. In a normal interest rate regime, an expansionary monetary policy shock raises the output gap as well as private consumption and investment in the short run. However, in a low interest rate regime, the responses of these variables to a monetary policy shock are reversed, suggesting that the substitution effects are weaker relative to the income effects in a low interest rate environment. The response of gross household savings provides evidence for a potential dominance of income effects in the low interest rate regime. While the savings volume decreases significantly after monetary policy expansion in the normal rate regime, it increases when monetary policy accommodation occurs in the low rate regime. This indicates that in a low interest rate environment further monetary policy easing could raise savings, which reflects a dominant income effect.

Overall, the results for the euro area indicate that the dynamics of transmission channels from monetary policy shocks to macroeconomic aggregates differs across the two interest rate regimes. This points towards the existence of a macroeconomic reversal interest rate and sheds new light on changes in the monetary policy transmission mechanism at the effective lower bound (ELB).

1. Introduction

An extended period of low interest rates may alter the transmission of monetary policy to various components of aggregate demand. The decade following the Global Financial Crisis (GFC) has been marked by historically low interest rates and this phenomenon is likely to persist. It is therefore crucial to understand whether the sensitivity of the economy to monetary policy rate changes is different in a low - compared to a normal - interest rate environment. A prolonged period of low interest rates may cause higher savings of firms and households due to negative income effects of low interest rates (Colciago et al., 2019). If these negative income effects dominate substitution effects, expansionary monetary policy may have a contractionary impact. At that juncture monetary policy hits the macroeconomic reversal rate, defined as the interest rate level at which further loosening of monetary policy becomes counter-productive in stimulating aggregate demand.

This paper examines nonlinearities in the monetary policy transmission mechanism by investigating whether the effects of monetary policy shocks change once the economy is in a low interest rate regime. For this purpose, we estimate a smooth transition local projections model for the euro area and its five largest countries and analyse whether the monetary policy transmission channels are regime-dependent. Specifically, we test whether the impulse responses of various aggregate demand components and the output gap to an expansionary monetary policy shock are different under two distinct regimes: normal and low interest rate.

We expect the link between aggregate demand and monetary policy to be state-dependent, because a prolonged period of low interest rates has implications for several channels of monetary policy transmission. First, the low-for-long interest rate environment alters consumption and savings patterns through the redistributive channel and the trade-off between substitution, income and wealth effects. Second, it affects investments in capital goods due to diminishing returns on those assets and changes in relative returns on financial assets.

The substitution and income effects refer to the redistributive channel of monetary policy, which works through income, cash flows and wealth (Borio and Hoffman, 2017). A combination of these factors determines the overall change in an individual's consumption and saving behavior in response to a change in the interest rate. The substitution and income effects depend on parameters of the utility function and the initial interest rate level, while the wealth effect depends on individual's preferences as well as on economic and financial market conditions. The wealth effect generally reinforces the substitution effect, as interest rate changes affect the present value of wealth and thereby shifts spending power of asset holders across time. The income effect is related to the financial income of households from deposit savings and financial assets. A low interest rate environment compresses financial income and could reinforce additional savings, for instance due to nominal savings targets of households. The income effect can also result from the impact of Quantitative Easing (QE) on bond yields. The decline in the term premium on bond yields due to QE has a negative effect on the expected future income stream of bond holders. Bond holders who expect a lower life-time income are likely to scale back their consumption.

The trade-off between income and substitution effects depends on the modelling of risk aversion in the agent’s utility function. In the standard power utility function, risk aversion is measured as the inverse of the elasticity of intertemporal substitution. This means that if the substitution effect increases, the income effect decreases proportionally. In alternative utility functions, for instance with Epstein-Zin utility, the risk aversion parameter is separated from the elasticity of intertemporal substitution, which allows calibrating both parameters independently (Epstein and Zin, 1989).

Persistently low interest rates may impact the redistributive channel in two possible ways. First, higher uncertainty about future income induces precautionary savings (Basu and Bundick, 2017; Guerrieri and Lorenzoni, 2017). If interest rates are persistently low, negative income effects may become more prevailing. In these circumstances, households are concerned that low returns on savings render their lifetime savings insufficient for retirement. In addition, worries about the value of pensions or life insurance products raise the need for additional savings. Consequently, the substitution effect may become weaker relative to the income effect at very low (positive or negative) levels of interest rates. Guerrón-Quintana and Kuester (2019) show that the income effect of an interest rate cut dominates the intertemporal substitution effect when countries have less generous retirement systems with low government-provided pensions, and when private savings of households become the main source of their retirement consumption. Uncertainty and nominal loss aversion may give rise to nonlinear responses of savers and investors to monetary policy shocks. A negative nominal interest rate may contribute to uncertainty as it may convey disappointing information about the economic outlook and expected asset returns. Such heightened uncertainty can induce economic agents to raise precautionary savings. This reinforces the negative income effects in a nonlinear way.

Second, interest rate changes influence aggregate demand through wealth effects (see e.g., Brunnermeier and Sannikov, 2012; Auclert, 2019). Declining interest rates boost asset prices, and changes in interest rates have a larger impact on asset prices at low interest rate levels (according to the dividend discount model). Thus, wealth effects would be stronger in a low rate environment, which could counterbalance the negative income effects on savings.

A prolonged period of low interest rates does not only affect consumption and savings patterns but can also have adverse effects on investments in capital goods through the bank lending channel. If banks' interest rate margins decline and thus their net worth diminishes, the reversal rate can be triggered (Brunnermeier and Koby, 2018; Eggertsson et al., 2019). At that point, a lower policy rate can lead to higher instead of lower lending rates and therefore actually reduce lending and investment. The reversal rate used by Brunnermeier and Koby (2018) refers to an earlier stage in the monetary policy transmission (via the banking channel) than the macroeconomic reversal rate channel we define in this paper, which relates to the effects of monetary policy on investments.

There is a rich literature analysing the transmission of monetary policy shocks and the relationship between interest rates and spending in a linear setting (see Section 2.4). However, the evidence on monetary policy transmission channels in a low interest rate environment remains scant. Our paper adds to the literature by considering nonlinearities in responses of economic variables to monetary policy shocks and distinguishing two interest rate regimes. We estimate a smooth transition local projections model similar to Tenreyro and Thwaites (2016). These authors examine nonlinearities in the monetary policy transmission for the U.S. under economic expansion or recession and find that fiscal policy has counteracted monetary policy in recessions but reinforced it in booms.

We investigate the state-dependence of monetary policy shocks and provide evidence on how an environment characterised by "low-for-long" interest rates may alter impulse response, especially for savings and investments. The smooth transition local projections method allows the effect of monetary policy shocks on the variables of interest (investment, savings, consumption, and output gap) to vary between low and normal interest rate regimes.

Furthermore, we focus on the comparison of the effects across the regimes and test whether they are significantly different. This analysis enhances our understanding of monetary policy transmission and its effectiveness at the zero lower bound (ZLB). We also estimate a standard linear specification in order to see how the unconditioned transmission channels work.

Our results point to the existence of a macroeconomic reversal rate, which could be explained by income effects becoming more dominant than substitution effects at low interest rate levels. In the normal interest rate regime, an expansionary monetary policy shock increases capital goods investment, private consumption and the output gap in the short run. In contrast, in a low rate regime, the responses of these variables to an expansionary monetary policy shock become negative, suggesting that the substitution effects are weaker relative to the income effects in a low interest rate environment.

The response of gross household savings provides evidence for a potential dominance of income effects in the low interest rate regime. The savings volume declines after a monetary easing shock in the normal rate regime, while it increases in the low rate regime. This indicates that in a low rate environment further monetary policy easing raises savings, which reflects a dominant income effect. Overall, our findings show that monetary policy transmission changes in a persistently low interest rate environment due to different dynamics in the responses of macroeconomic aggregates to monetary policy shocks across the two interest rate regimes.

The rest of the paper is structured as follows. Section 2 discusses the related theoretical literature and previous empirical evidence. Sections 3 and 4 describe the methodology and data, respectively. Section 5 presents the baseline results, while Section 6 provides the sensitivity analysis. Section 7 concludes with a summary and policy implications.

2. Literature review

2.1. Macroeconomic reversal rate

Substitution and income effects in a low interest rate environment can be assessed in a standard representative agent New-Keynesian (RANK) model. In the RANK framework, the ZLB is treated as a nominal friction that can prevent an equilibrium between supply and demand (see e.g., Eggertsson and Woodford, 2003; Benigno and Fornaro, 2018; Galí, 2018). Adverse demand shocks can then lead to a savings surplus, which causes the equilibrium interest rate to fall below zero. When the ZLB is binding, higher uncertainty about future income induces precautionary savings by risk-averse households, leading to a drop in consumption and output as well as a higher probability of falling into a liquidity trap (Basu and Bundick, 2017; Guerrieri and Lorenzoni, 2017). If the central bank is not able to reduce the policy rate below the equilibrium rate due to the ZLB, a recession is likely to follow. The equilibrium can be restored by reducing the real policy rate via higher inflation expectations (Schmitt-Grohé and Uribe, 2017; Jarociński and Maćkowiak, 2018) or fiscal policy expansion (Eggertsson, 2010; Christiano et al., 2011). In this framework, a negative equilibrium interest rate is the result of the savings surplus and not of monetary policy.

Recent studies criticize the standard RANK framework and the loanable funds model on which it is based. Palley (2019) shows that lowering the policy rate into the negative territory does not provide an additional stimulus but drives the economy further away from equilibrium. A negative nominal interest rate functions like a macroeconomic reversal rate, which stimulates savings and discourages investments in capital goods ('investment saturation'). In Palley's model, investments and savings are driven by nominal interest rates. Agents borrow because they are liquidity constraint (cash-in-advance constraint), for which nominal debt service payments are relevant.

A key role in Palley's (2019) model is played by non-reproduced assets (NRAs), i.e. assets that are in short supply, such as cash, commodities, land, and monopoly rents. If the marginal nominal return on NRAs is above zero (which he assumes to be the lower bound of NRA returns[1]), while the return on investments in capital goods falls below zero, savings (loanable funds) are diverted to NRAs. This state of the economy is associated with investment saturation. Expansionary monetary policy then creates more loanable funds flowing towards NRAs rather than to capital goods investments and generates asset price inflation through financial risk-taking.

In a state of investment saturation, capital goods investments are no longer responsive to changes in the monetary policy rate, i.e. the demand curve is inelastic (see Figure 1). The curve

[1] Palley's (2019) choice to put the threshold, under which resources are diverted to NRA's, at zero is somewhat arbitrary. The return on investment can become negative due to replacement costs. The marginal return on NRA's also moves to zero if the policy interest rate falls but cannot become negative (although an increasing demand for scarce assets results in asset price inflation, which lowers expected returns). Due to the assumed ZLB in the marginal return on NRA's, under a negative policy interest rate all liquidity is flowing to NRAs.

can even bend backwards and become reversely elastic with respect to the interest rate, implying that investment demand falls if the rate decreases. The backward-bending part of the demand curve can be associated with negative marginal returns on capital, reflecting a negative natural interest rate. The more negative the marginal returns become, the more investment demand will fall.

McKay and Wieland (2020) find evidence for a similar channel as investment saturation. They simulate the effect of monetary policy shocks in a dynamic stochastic general equilibrium (DSGE) model and find that intertemporal shifting is less strong in the ZLB period (which is akin to a low interest rate regime). They explain their finding by monetary policy borrowing demand from the future. This is an intertemporal shifting effect, whereby higher investment today increases the future capital stock, which subsequently reduces marginal benefits from investing in the future. It implies that monetary policy has decreasing marginal effects. McKay and Wieland (2020) do not find a reversal of the monetary policy effect, possibly because they do not consider financial channels for negative income effects.

In Palley's (2019) framework a negative nominal interest rate is also associated with a rise in savings. This situation is reflected in the negatively sloping savings curve in Figure 2, from the point where the interest rate drops below zero. In those conditions, the negative income effect of a negative interest rate (driven by negative nominal returns on bank accounts or diminishing pension wealth) dominates the usual substitution effect.

Figure 1. Investment demand

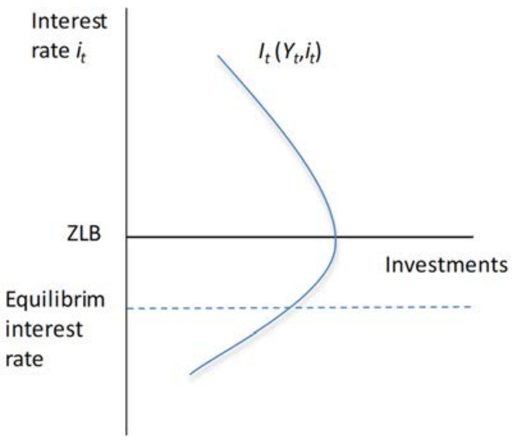
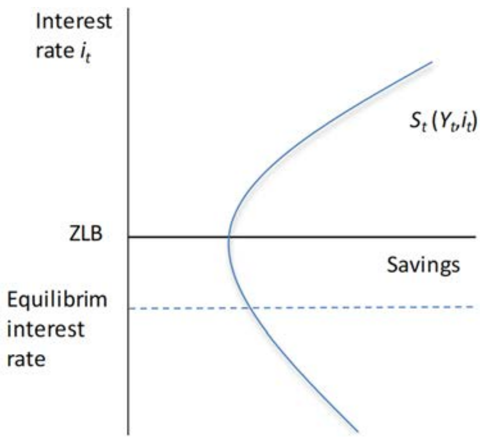


Figure 2. Savings supply



2.2. Financialization

Another view is offered by Bofinger and Ries (2017) who criticize the loanable funds model and assume that if investments in capital goods stay behind, loose monetary conditions stimulate speculative financial activities. Along this channel, low or negative interest rates have adverse consequences, which are driven by monetary policy and bank lending. Bofinger and Ries (2017) explain the reduced elasticity of investments with respect to low or negative interest rates outside the loanable funds framework. In their endogenous money model, a low interest rate is not (exogenously) driven by a savings surplus, but endogenously by loose monetary policy conditions (Borio et al. (2019) make a similar argument). Such conditions stimulate credit supply by banks which – different from the loanable funds model – create money. In this way, a low interest rate arises from a 'financing glut' and not from a 'savings glut'. This view is linked to the banking glut hypothesis of Shin (2012), who explains the easy credit conditions in the U.S. by a surge in gross bank capital inflows.

In the framework of Bofinger and Ries (2017), buoyant credit supply boosts (speculative) financial activities and not so much the real economy. This is also related to weak demand for capital goods investments. Weak investment demand is explained by low wage growth, higher income and wealth inequality (capital gains are concentrated among a small group of agents at the top of the wealth distribution (Gornemann et al., 2016)), uncertainty, and financialization. The latter means that firms increasingly borrow funds to purchase financial assets and finance mergers, acquisitions and divided payments, rather than to fund new capital goods investments (Onaran et al., 2011; Van Arnum and Naples, 2013). Financial activities are further stimulated by the low interest rate policy of the central bank. The financialization implies that investment demand becomes less sensitive to interest rate changes in a low interest rate environment.

2.3. Implications

The loanable funds and the endogenous money frameworks, discussed above, differ in the assumed drivers behind low and negative interest rates. In the former the savings surplus is a dominant driver, while in the latter loose monetary policy determines the low interest rate. Nonetheless, in both frameworks the demand for capital goods investments becomes less responsive to a declining interest rate or is being hindered by it. This points to a macroeconomic reversal rate, defined as the interest rate level at which a further loosening of monetary policy becomes ineffective in stimulating aggregate demand.[2] The relative attractiveness of financial activities in a low or negative interest rate environment plays an important role in this mechanism. These insights challenge the relationship between aggregate demand and the interest rate in the standard RANK model.

2.4 Previous empirical evidence

There is an extensive literature which examines the transmission of monetary policy shocks and the relationship between interest rates and spending in a linear setting. For instance, Ascari et al. (2021) use aggregate U.S. data over a long time span to estimate the consumption-interest rate relationship while controlling for returns of wealth portfolio, habit formation, and a sizable fraction of hand-to-mouth consumers. Their results vary depending on the particular interest rate used. In the model with the risk-free rate (i.e., Federal Funds rate), consumption does not react to changes in the real interest rate. When the risk-free rate is replaced by the stock market return to capture a degree of risk aversion, the coefficient is significantly greater than zero. In addition, their results are insensitive to using linear versus nonlinear specifications.[3] In OLS estimations for G7 economies over the period 1982-1998, Goodhart and Hofmann (2005) report that the real interest rate has a significant negative effect on the output gap when the model controls for asset prices and monetary aggregates. Similarly, Angeloni and Ehrmann (2007) analyse 12 euro area countries during 1998-2003 and find that the effect of the real interest rate on consumption is significant at the 10% level.

These studies do not explore the impact of monetary policy shocks on specific aggregate demand components - savings, consumption and investment - and do not examine whether the monetary transmission changes in a low interest rate environment. A paper close to ours is by Hofmann and Kohlscheen (2017). They examine the relationship between consumption growth

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[2] Another potential driver behind the diminished sensitivity of aggregate demand to the interest rate and the altered monetary policy transmission is related to structural changes in the economy, such as a growing share of services since the early 2000s (Herrendorf et al., 2013; Galesi and Rachedi, 2019). In an economy that is increasingly dominated by services rather than by capital intensive industries, the cost of finance is less important for aggregate demand. We take this factor into account in our sensitivity analysis, where we include in our model the share of services in GDP as an additional control variable.

[3] Note that nonlinearity considered in Ascari et al. (2021) refers to nonlinearity due to model parameters and does not account for nonlinearity due to different interest rate regimes. The latter is the specific focus of our paper.

and interest rates and account for nonlinearities using piece-wise regressions, which allow the interest rate semi-elasticity to vary across different thresholds of the interest rate. The authors find that the semi-elasticity of consumption to interest rate changes increases with the interest rate level, suggesting that the relationship flattens at low rates. However, their approach does not allow for identifying distinct interest rate regimes and cannot examine the dynamic reaction of consumption to interest rate changes. In addition, they focus only on consumption. Moreover, using interest rates directly in the model estimation can lead to inconsistent estimates due to the endogeneity problem generated by reverse causality.

3. Empirical model

This section presents the methodology employed in our paper to estimate the nonlinear effects of monetary policy shocks on macroeconomic aggregates. Assuming that monetary policy is forward looking, the literature takes a simultaneity bias into account, usually by an instrumental variable approach (e.g. Fuhrer and Rudebusch, 2004). Such an approach is also applied in studies that deal with a similar endogeneity problem in the estimation of a New Keynesian Phillips curve model (Kleibergen and Mavroeidis, 2009).

We use a different approach and take into account the possible endogeneity between interest rates and spending by employing exogenous monetary policy shocks, constructed for the euro area by Jarociński and Karadi (2020) (JK2020, henceforth). Using shocks instead of ex-ante or ex-post interest rates implies that our model does not distinguish between backward- or forward-lookingness, but rather offers a hybrid version with elements of both approaches. Given that monetary policy shocks are identified using past observations of macroeconomic and financial variables, they capture a backward-looking component. At the same time, our model has an element of forward-lookingness, since the shocks of JK2020 are based on market interest rates and stock prices, and thereby capture market expectations (also on inflation).

The state dependence is modelled by a smooth transition local projections model, as in Tenreyro and Thwaites (2016) who adapt the local projections method of Jordà (2005) to estimate impulse responses of economic variables to monetary policy shocks in recessionary and expansionary regimes[4]. In our context, the smooth transition model allows the elasticity of intertemporal substitution β and other parameters to vary across two regimes as defined by different interest rate levels (low and normal interest rate regimes). Specifically, we estimate the following equation (1):

$$y_{t+h} = \tau t + F(z_t)\left(\alpha_h^l + \beta_h^l mps_t + \gamma_{h,p}^l L(p)X_t'\right) + (1 - F(z_t))(\alpha_h^n + \beta_h^n mps_t + \gamma_{h,p}^n L(p)X_t') + \varepsilon_t \qquad (1)$$

where y_{t+h} is a dependent variable denoting investment, savings and consumption (all in log-levels), or the output gap in period $t + h$; $h = 0,1,2, \dots H$ is a projection horizon, set to 16 quarters; mps_t is a monetary policy shock, included contemporaneously to derive the policy relevant semi-elasticity. X_t' is a vector of controls; τ is a linear time trend, α_h is a constant, and ε_t is an error term with mean 0. $L(p)$ is a lag polynomial of degree p. As controls we include lags of the dependent variable. In a sensitivity analysis we also include other control variables. The number of lags p is set to one, based on the Bayesian information criterion (BIC) for the optimal lag length.[5]

All parameters including the ones capturing the effects of the monetary policy shock (β_h^l, β_h^n) differ across the two regimes: a low (l) and a normal (n) interest rate regime. The probability of being in either regime is determined by the smooth increasing transition function $F(z_t)$ of an indicator of the state of the economy z_t. In our analysis, $F(z_t)$ is modelled as a logistic function of the interest rate as a state variable, taking the following form:

$$F(z_t) = \frac{\exp\left(-\theta \frac{(z_t - c)}{\sigma_z}\right)}{1 + \exp\left(-\theta \frac{(z_t - c)}{\sigma_z}\right)} \; , \qquad (2)$$

where c is a threshold capturing a proportion of the sample for which the economy is in either regime and σ_z is the standard deviation of the state variable z_t. Parameter θ denotes the speed of transition, measuring how fast the economy switches from a normal rate regime to a low rate regime when z_t changes. $F(z_t)$ is a continuous function bounded between 0 and 1. When $F(z_t)$ goes to 1 (0), there is a high probability of being in a low (normal) interest rate regime.

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[4] The same approach is applied by Auerbach and Gorodnichenko (2011) and Ramey and Zubairy (2018) to analyse the effects of fiscal policy shocks on GDP growth.

[5] Our model includes all the response and control variables in log-levels, in order to be consistent with our theoretical framework. As a robustness check, we re-estimated STLPs with all variables, except for the output gap and interest rates, included in log-differences (see Section 6).

A low rate regime is distinguished from a normal rate regime by the threshold value c of the interest rate. The threshold is calibrated such that a low interest rate regime occurs in around 20% of the sample.[6] The threshold value c is different for different economies and different measures of the interest rate (nominal or real, short- or long-term). We check the robustness of our results to various calibrations of this parameter in Section 6.

The speed of transition (θ) between the low and normal rate regime is calibrated by assessing how binary the indicator function is desired to be. Following Auerbach and Gorodnichenko (2011) and Tenreyro and Thwaites (2016), we calibrate rather than estimate the parameters of the smooth transition function, as "it is difficult in practice to identify the curvature and location of the transition function in the data" (Tenreyro and Thwaites, 2016, p. 50). For this reason, the estimation of the parameters of function $F(z_t)$ is not common in the literature.[7]

The local projections model is estimated based on the ordinary least squares (OLS). We account for serial correlation in the error terms by using the Newey-West standard errors. The estimated coefficients β_h provide enough information to construct impulse responses of a dependent variable to a contemporaneous monetary policy shock. The impulse responses show the ($100*\beta_h$)% change in the dependent variable y_{t+h} at horizon h following a one standard deviation negative (expansionary) monetary policy shock at time $t = 0$. We estimate both the linear version of the model (which does not distinguish between interest rate regimes, i.e. $F(z_t)$ = 1) and the state-dependent model (based on the distinction between low and normal interest rate regimes, i.e. $0 < F(z_t) < 1$).

The local projections approach has several advantages compared to a typical VAR model. It does not impose specific dynamics on the variables, it does not suffer from the curse of dimensionality inherent to VAR models, and it can be easily be adapted to include nonlinearities (see Jordà, 2005; Barnichon and Brownlees, 2019).

[6] We follow Auerbach and Gorodnichenko (2011), Ramey and Zubairy (2018) and Tenreyro and Thwaites (2016), who define a recession as the lowest 20 percent (in terms of GDP growth) of the periods in the sample. We define a low interest rate regime as the lowest 20 percent (in terms of the interest rate level) of observations in our sample.

[7] Granger and Teräsvirta (1993) suggest using a grid search, because the estimated values could be very sensitive to few observations of the sample. The grid search in this case is similar to a calibration method. We check sensitivity of the results for different parameter values of a smooth transition function in the robustness section.

4. Data

Our sample covers quarterly data for the euro area and its five largest countries – Germany (DE), France (FR), Spain (ES), Italy (IT) and the Netherlands (NL) - over the period 1999q2 - 2019q1. For the euro area aggregate and the individual countries we use the same monetary policy shock given that the euro area member-states share a common monetary policy.

4.1. Variables selection

The interest rate regimes defined in the smooth transition function $F(z_t)$ are determined by various interest rate measures. In the baseline specification we use nominal and real short-term interest rates. These are 3-months interbank rates, deflated by HICP inflation to construct the real rate. In the robustness section we also use a nominal long-term interest rate proxied by 10-year government bond yield and a nominal bank lending rate (average lending rate on loans to firms and households). In addition, we also include the shadow rate from Krippner (2015) as a state variable, since it is used as a proxy for monetary policy stance to capture unconventional measures adopted by the ECB during the period of the effective lower bound. Applying different interest rate measures in the smooth transition function means that the timing of the low interest rate regime may also differ. This implicitly tests for the sensitivity of the results to other factors than the interest rate regime, such as periods of financial crisis.

We measure y_t by various components of aggregate demand, such as total private investments in capital goods (equipment and machinery), total private consumption, private consumption of durable goods and the output gap. The responses of these variables to monetary policy changes may reflect the *substitution effects*. All variables (except the output gap) are seasonally adjusted volumes in mln EUR. To capture the *income effects,* we include the gross household savings volume in mln EUR. We are aware that this is not a perfect indicator of income effects, given that savings are not only affected by the interest rate, but also by wider implications of low interest rates on employment and income as well as by changes in households' asset portfolios. Hence, only if savings move in the opposite direction - predicted by the intertemporal substitution effect - it may signal that adverse income effects are present. For a preliminary analysis we also use real GDP (chain-linked volumes (2015) in mln EUR, seasonally and calendar adjusted) and the HICP index (2015=100).

As additional control variables we include financial assets (measured as total financial assets of households, including pension wealth), stock prices and house prices deflated by HICP inflation. Stock prices are based on the national stock index; house prices are residential property prices. To control for global and structural factors that may have driven the decline in interest rates in recent decades, we include the share of services in nominal GDP.

The time series for macroeconomic, financial, and interest rate variables are obtained from OECD Statistical Database, the ECB SDW, and Eurostat, complemented with national sources. The output gap is sourced from the Oxford Economics database. All variables are transformed into log-levels, except for the output gap, interest rates, and monetary policy shocks.

4.2. Monetary policy shocks

As a benchmark for our analysis we use the monetary policy shock from JK2020, updated until March 2019.[8] The authors use a sign restrictions identification approach and separate monetary policy shocks from contemporaneous central bank information shocks by analysing a high-frequency co-movement of interest rates and stock prices in a narrow window around monetary policy announcements. Specifically, a monetary policy shock is identified by a negative co-movement between the interest rate and stock price changes. The methodology of JK2020 is closely related to a proxy VAR approach (Mertens and Ravn, 2013; Stock and Watson, 2018) that uses high-frequency interest rate surprises as external instruments to identify monetary policy shocks (Gertler and Karadi, 2015). The surprises are constructed using intraday variation around the ECB policy announcements in EONIA interest rate swaps and the EURO STOXX 50, a market capitalization-weighted stock market index including 50 blue-chip companies.[9]

As a robustness check we employ two alternative shocks. First, besides the benchmark monetary policy shock from JK2020 identified via the baseline sign restrictions approach, we use their monetary policy shock identified by additionally assuming that in each month only a pure monetary policy shock or a pure central bank information shock takes place ("poor man's" identification). In contrast, in the baseline sign restrictions approach the assumption is that in

[8] Quarterly shocks in our paper are calculated as summation of monthly shocks over three months of the corresponding quarter. We thank Marek Jarociński for sharing the monthly data on monetary policy shocks.

[9] The interest rate surprise in JK2020 is the first principal component of surprises in interest rate derivatives with maturities 1 month, 3 months, 6 months, and 1 year. The surprises in interest rates and stock prices are constructed based on Thomson-Reuters Tick History dataset.

each month a combination of the two shocks (i.e., monetary policy shock and central bank information shock) is observed with different, non-zero shares. We investigate how the responses of key variables are influenced by this alternative identification.

Second, we use the central bank information shock from JK2020. Their monetary policy shock is identified by assuming no correlation between the two shocks over the sample, but their sample is somewhat different from ours. Therefore, we examine how the responses of our key variables differ for a central bank information shock compared to a monetary policy shock.

5. Empirical results

This section presents the main results for linear and state-dependent models. In both models we only use the lagged dependent variable as a control.[10] The interest rate regimes in the state-dependent model are defined using the nominal or real short-term interest rate as a state variable in the smooth transition function. We examine the impulse responses to a one standard deviation negative shock, which reflects an expansionary monetary policy shock.

Overall, our results point to significant changes in monetary policy transmission across the two regimes, as the impulse response functions are significantly different in the normal rate regime compared to the low rate regime. We find that investments, consumption and savings respond to an expansionary monetary policy shock in opposite directions across the regimes.

In the normal rate regime, an expansionary monetary policy shock increases investment volume in the euro area. However, in the low rate regime the responses are reversed, implying that in a low interest rate environment further monetary easing might not stimulate investment, but actually discourage it. This result is in line with our theoretical framework and previous studies (e.g. Bofinger and Ries, 2017; Palley, 2019), which point to the reversal of investment behaviour in a low rate environment due to negative marginal returns on capital and/or financialization. The results for consumption are comparable to the ones for investment in terms of signs of responses, although the magnitude of the estimated effect is smaller.

Next, in the low rate regime savings volumes respond differently to a monetary policy shock than in the normal rate regime. In the low rate regime savings significantly increase after an expansionary monetary shock. These findings are consistent with Palley's (2019) model and

[10] We show in the robustness section that adding more controls does not substantially affect the results.

indicate that in a low interest rate environment further monetary policy easing would raise savings due to negative income effects.

5.1 Main analysis

We first present our main hypotheses for spending and savings, based on the theoretical framework discussed in Section 2. According to the substitution effect, the response of spending, and its investment component in particular, is expected to be positive in the normal rate regime, implying that an expansionary monetary policy shock is associated with higher spending. The substitution effect might take some time to unfold, in line with the usual lags in monetary policy transmission. Therefore, we assess the impulse responses over a medium-term horizon (16 quarters). In the low rate regime, we expect spending to behave differently. Based on the discussed literature, we conjecture that the response of spending to an expansionary monetary shock in a low rate regime would change sign, pointing to a reversal of spending behaviour in a low interest rate environment.

Our priors for the response of savings are based on the assumed income effects. In the normal rate regime, an expansionary monetary policy shock is expected to reduce savings, in line with theory. In the low rate regime, the response of savings is expected to reverse and become positive, implying that further monetary easing stimulates savings once the economy is at the ZLB. This would indicate that income effects dominate substitution effects.

We test our conjectures empirically. Figures 3-4 show the impulse responses for the euro area. The responses for the five countries are displayed in Figures A2-A6 in the Appendix.[11] First, we report the results for investments and savings, consistent with our theoretical framework in Section 2. Next, we discuss consumption as another spending component. Lastly, we show the results for the output gap as a general macroeconomic indicator.

[11] As a robustness exercise, we employ the panel estimation approach by pooling observations for 5 EA countries. That is, instead of estimating responses using EA aggregate data, we estimate mean responses across individual EA countries. We use Driscoll and Kraay (1998) standard errors, suitable for large T and small N panels. Additionally, we use a two-way fixed effects (FEs) estimator where FEs are interacted with the respective state probabilities. Overall, the responses from the panel data are similar to the ones for the EA aggregate, although in the low rate regime the confidence bands are slightly wider in some cases (see Figure A7 in the Appendix).

5.2 Investments and savings

The impulse responses of capital good investment to an expansionary monetary policy shock are positive and significant for the euro area and all individual countries in the linear model (see Figure 3 (a-b) and Figures A2-A6 (a-b)). A one standard deviation monetary easing shock implies an increase in investment by 2% in the euro area (2-3% in individual countries) at the peak, reached 4 quarters after the shock. The positive effect stays significant for up to 2 years.

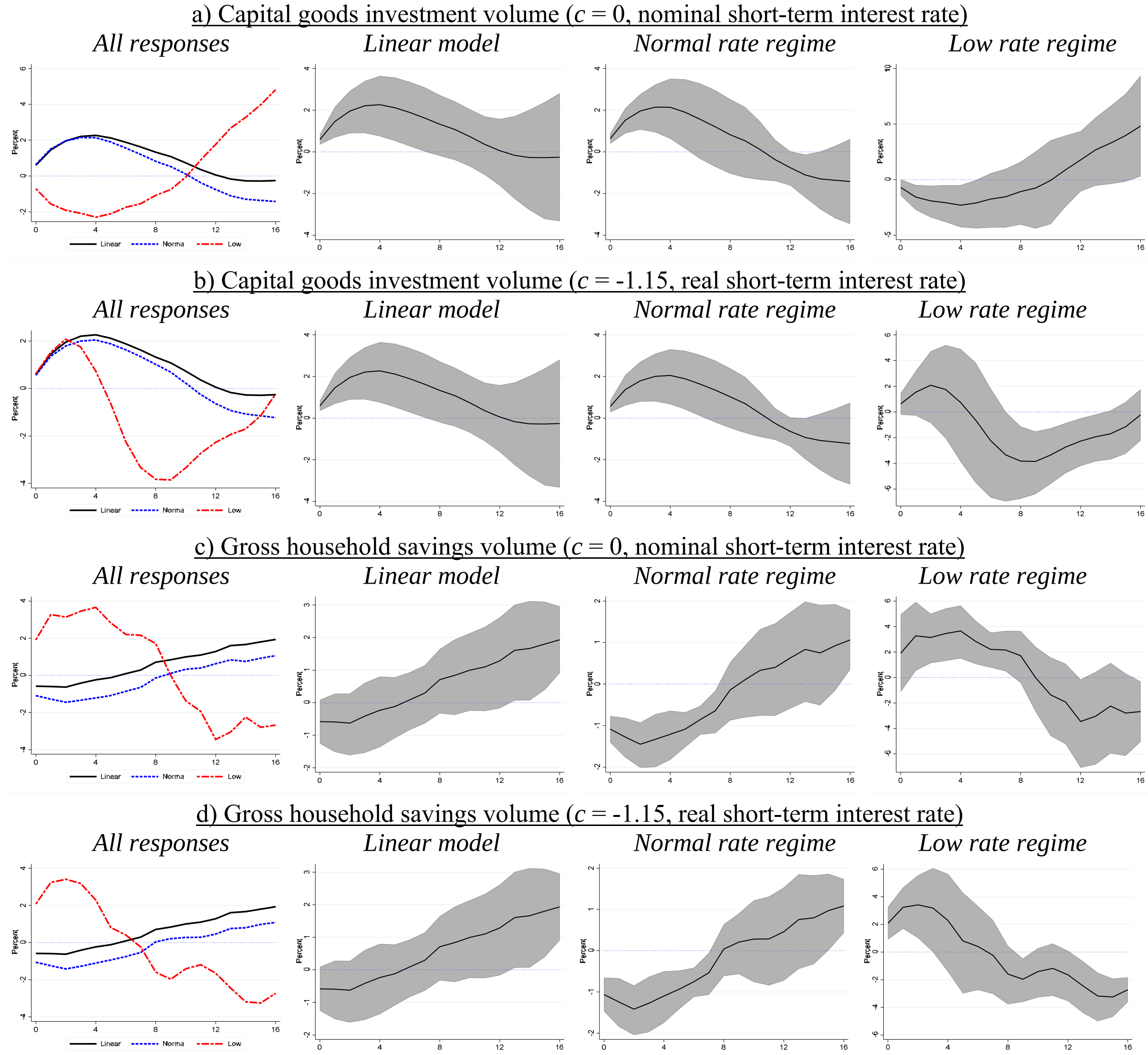
In the normal rate regime, an expansionary monetary policy shock raises private investment in the euro area by 2% at the peak and the effect endures over 4 quarters. Similar responses are reported for individual countries, albeit of varying magnitudes. In the low rate regime, the responses are reversed for the euro area and most countries. The investment volume for the euro area declines significantly after an expansionary monetary shock by -2% at the trough and the negative effect lasts for 2 years.[12] The impulse responses of investment in the normal and low rate regime are significantly different for the entire horizon. This result is in line with our hypothesis that the response of investment reverses in a low interest rate environment.

The impulse responses for savings display the opposite dynamics (see Figure 3 (c-d) and Figures A2-A6 (c-d)). In the linear model and in the normal rate regime gross household savings decline immediately after an expansionary monetary policy shock by up to -0.5% and -1.5% at the trough, respectively. This effect in the normal rate regime stays negative and significant for 8 quarters. The result holds for the euro area, Spain, and the Netherlands, while the responses are insignificant for Germany, France, and Italy.

In the low rate regime savings strongly increase after an expansionary monetary shock. This is found for the euro area, Germany, France, Italy, and Spain, where the responses remain positive and significant for up to 2 years. In the euro area, the magnitude of the savings' rise in the low rate regime (4% at the peak) is larger than the savings' drop in the normal rate regime (-1.5% at the trough). These findings are in line with our hypothesis on the income effect, indicating that in a low interest rate environment further monetary policy easing would raise savings. It reflects that the income effect becomes stronger relative to the substitution effect.

[12] In Germany, France, and Italy significant negative effects are found when the low rate regime is defined by the nominal short-term rate, while the corresponding responses are insignificant in Spain and the Netherlands.

Figure 3. Impulse responses of y_{t+h} (investments and savings) to one st. dev. expansionary monetary policy shock, euro area



Notes: The figure plots the smoothed impulse responses of capital goods investment and gross household savings (all in log-levels) to a one standard deviation expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear, state-independent model, the blue dashed line - the response in the normal interest rate regime, and the red dash-dotted line - the response in the low interest rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

The first columns in Figures 3 and A2-A6 (Appendix) show the median impulse responses of investment and savings based on the linear and state-dependent models. These graphs indicate that responses in the normal and low interest rate regimes are noticeably different. To evaluate whether this difference between the two regimes is statistically significant – which would indicate the existence of nonlinearity - we apply a joint Chi-squared test of differences in coefficient estimates of the impulse responses. The Chi-squared test (also called a path test) is based on estimates with clustered standard errors.[13] The results of the test (see Table A1 in the Appendix) show that the median responses of investment and savings between the normal and low rate regimes are significantly different. Thus, we can reject the null hypothesis that the impulse responses in both regimes are similar, implying that there is significant nonlinearity in the estimated effect of monetary policy shocks on investment and savings.

5.3 Consumption and output gap

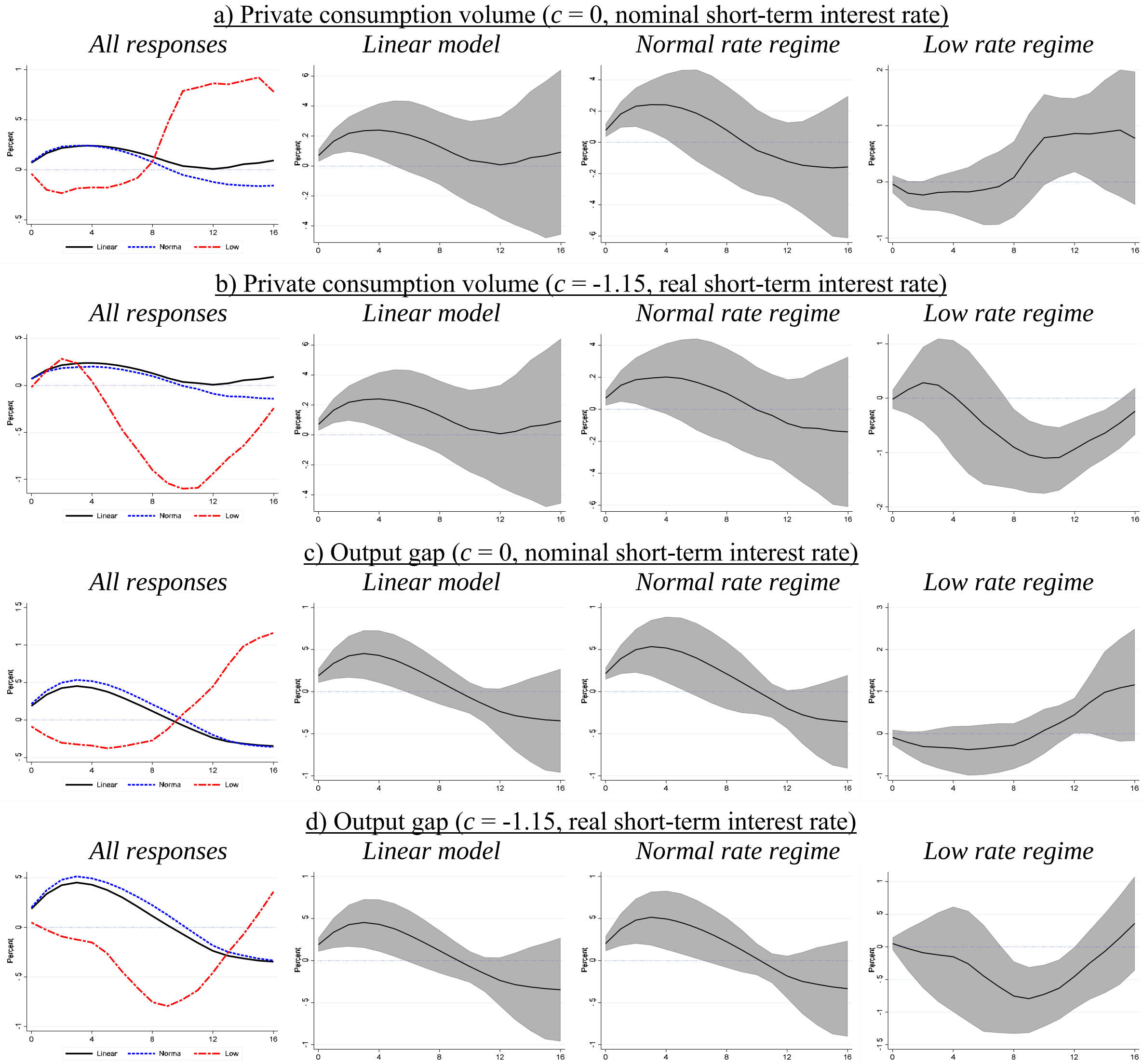
This section discusses the results for the other two dependent variables: private consumption and the output gap. The findings for consumption are comparable to the ones for investment in terms of signs of responses, although the magnitude of the estimated effect is much smaller (see Figure 4 (a-b) for the euro area and Figures A2-A6 (e-f) for individual countries). Total private consumption increases significantly after an expansionary monetary policy shock in the linear model in all analysed economies. The responses vary between the normal and low interest rate regimes. In the normal rate regime, an expansionary shock raises consumption in the euro area by 0.2% at the peak; this response is short-lived and significant for one year. In individual countries the increase in consumption is 0.4-0.8% and stays significant for 4-8 quarters on average. In the low rate regime, the response of consumption is weaker and less significant. For the euro area, consumption declines by around -0.2% at the through after an expansionary monetary policy shock. We also find a significant negative response of private consumption in the low rate regime defined by the nominal short-term rate for Germany, Italy, and Spain, while the effect for France and the Netherlands is not evident.[14]

Overall, these results suggest that the behaviour of consumption following a monetary policy shock supports the hypothesis on substitution effects: in the normal rate regime consumption increases, while it behaves in the opposite way in the low rate regime. This implies that in a low interest rate environment further monetary easing might not stimulate private consumption but reduce it.

[13] The results using clustered standard errors are qualitatively similar to the ones we obtain using Newey-West standard errors, in terms of statistical inference and significance of the estimated impulse responses.

[14] As an alternative, we examine total private consumption of durable goods in the individual euro area countries (such data are not available on the aggregate euro area level). The impulse responses of this variable are qualitatively comparable to the ones obtained for total private consumption (results are available upon request).

Figure 4. Impulse responses of y_{t+h} (consumption and output gap) to one st. dev. expansionary monetary policy shock, euro area



Notes: The figure plots the smoothed impulse responses of total private consumption (in log-level) and the output gap to a one standard deviation expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear, state-independent model, the blue dashed line - the response in the normal interest rate regime, and the red dash-dotted line - the response in the low interest rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

The impulse responses of the output gap point to a significant positive effect of a monetary easing shock in the linear model, which holds for the euro area (see Figure 4 (c-d)) and all individual countries (see Figures A2-A6 (g-h)). An expansionary monetary policy shock raises the output gap in the euro area by 0.5% at the peak, reached 4 quarters after the shock; this response stays positive and significant for 6 quarters. Similarly, for individual countries the output gap rises after an expansionary shock and this effect endures for up to 2 years.

The state-dependent model produces markedly different responses in the two regimes. In the normal rate regime, an expansionary monetary shock implies a rise in the output gap by 0.5% at the peak for the euro area. The response persists for a horizon of 4-8 quarters, in all analysed economies. This result confirms our hypothesis on the substitution effects. In the low rate regime, the response of the output gap is weakly significant and negative in the euro area, reaching -0.3% at the trough (for the nominal short-term rate as the state variable). For individual countries some specifications also generate responses that are significant with a reversed, negative sign. These results suggest that in a low interest rate environment the substitution effect becomes weaker relative to the income effect.

The impulse responses of private consumption and the output gap to an expansionary monetary policy shock in the euro area in the normal and low rate regimes are also considerably different from each other. A joint Chi-squared test confirms the statistically significant difference (see Table A1 in the Appendix). This provides evidence for existence of nonlinearity in the impact of monetary policy shocks on private consumption and the output gap.

The heterogeneous outcomes across the individual euro area countries are likely to be related to country-specific differences in monetary policy transmission channels. For instance, differences in financial structures (e.g. reliance on capital funded versus pay-as-you-go pensions), banking sector characteristics, or loan contracts (e.g. fixed versus floating interest rate terms) across countries may partially explain the heterogeneity in transmission of monetary policy shocks in individual economies. In addition, differences in countries' income and wealth composition and distribution across the population can be a determining factor for shaping the responses of aggregate demand in particular countries.

6. Sensitivity analysis

6.1 Preliminary analysis

We check how the monetary policy shock of JK2020 impacts standard macroeconomic variables. For this purpose, we estimate the linear and state-dependent local projections models for the euro area with real GDP, HICP and real stock prices (all in log-levels) as dependent variables in equation (1). The interest rate regimes in the nonlinear model are defined by the nominal and the real short-term interest rate. The estimated responses are reported in Figure A8 in the Appendix.

We find that a one standard deviation expansionary monetary policy shock leads to an increase of real GDP by 0.5-0.7% at the peak 5 quarters after the shock in the linear model and in the normal rate regime. This effect endures for up to 2 years. In the low rate regime, we observe an opposite dynamics: GDP drops by -0.5% at the trough, and the effect is significant and negative for 8 quarters. The results for HICP are qualitatively similar – an expansionary monetary shock implies a peak rise in HICP by 0.2% in the linear model and by 0.1% in the normal rate regime (in the nonlinear model with the regime determined by the nominal short-term rate). This positive effect stays significant for 1.5 years. The responses in the low rate regime are insignificant when the state variable is the nominal short-term rate, and positive in the alternative specification with the real short-term rate.

Real stock prices increase immediately after an expansionary monetary policy shock by 4% in the linear model and by 6% in the normal rate regime. This effect remains positive and significant for one year and gradually dies out. In the low rate regime, the response is reversed: a monetary easing shock leads to a drop in stock prices by 10% at the trough, which is particularly evident from the model with the real short-term rate as a state variable. Generally, the results for the linear model are in line with theory and previous empirical evidence. Based on these outcomes we conclude that the employed monetary policy shocks are well identified and therefore suited for our empirical setting.

6.2 Different shocks

We explore the robustness of our results to the employed shocks. First, we check whether the estimated effects are sensitive to the modified identification of a monetary policy shock as well as to the use of a central bank information shock. Second, we test whether the responses to the baseline monetary policy shock are asymmetric. The robustness checks are conducted for the two key dependent variables, investment and savings, using the nominal short-term rate as state variable in the smooth transition function (the results for other specifications and variables are available on request).

We employ the alternative monetary policy shock, identified in JK2020 by adding an assumption that in each month only a pure monetary policy shock or a pure central bank information shock takes place ("poor man's" monetary policy shock). The impulse responses of investment and savings to this shock are similar in terms of sign and magnitude to the ones obtained using the baseline monetary policy shock, albeit with wider confidence bands (see Figure A9 in the Appendix). Investment volumes increase after an expansionary monetary shock in the linear model and in the normal rate regime but decline in the low rate regime. The opposite holds for savings: they show a negative response in the normal rate regime and a positive one in the low rate regime.

Next, we employ a central bank information shock from JK2020 instead of a monetary policy shock. Based on the baseline sign restrictions used for identification of these shocks and a low negative correlation between the two (correlation coefficient of -0.13 in our sample), we expect that the two shocks behave differently and would induce a different reaction of the macroeconomic variables. Figure A10 in the Appendix confirms this conjecture: the impulse responses of investment and savings to an expansionary central bank information shock have the opposite signs than the corresponding responses to an expansionary monetary policy shock. This is evident in the linear model and in the normal rate regime, while in the low rate regime the responses are insignificantly different from zero. This finding is in line with JK2020 who report that the responses of the macroeconomic and financial variables to a central bank information shock have the opposite sign compared with the responses to a monetary policy shock. This also suggests that our estimated effects using a monetary policy shock are not due to the surprise impact of central bank announcements.

As an additional sensitivity test, we check whether the responses to monetary policy shocks are asymmetric. Several papers find that effects of positive monetary policy shocks (i.e. monetary tightening) on economic activity and the financial system can be larger than effects of negative monetary policy shocks (i.e. monetary easing) (see e.g. Santoro et al., 2014; Tenreyro and Thwaites, 2016; Barnichon and Matthes, 2018). The asymmetry in the monetary policy transmission can be caused by a number of factors, such as downward price and wage rigidity, credit market imperfections, high borrowing costs in downturns, and banks' balance sheet constraints, among others (Bernanke and Gertler, 1995; Florio, 2004; Barnichon et al., 2017). We test the asymmetry by examining whether positive monetary policy shocks have a different impact on the analysed macroeconomic variables compared to negative shocks.[15] We find no evidence for asymmetric effects of the (benchmark) monetary policy shocks as the impulse responses to positive and negative shock series in the euro area are very similar in terms of magnitude (results available on request).

6.3 Parameters of the smooth transition function

We examine the robustness of the findings to modifications of the calibrated parameters in the smooth transition function $F(z_t)$, i.e. the threshold values c of the state variable and the speed of transition θ. The robustness checks are applied to the baseline model (equation 1) for the euro area with investment or savings as dependent variables (results for other dependent variables and for individual countries are available on request).

Figure A1 in the Appendix shows the probability of being in the low or normal interest rate regime (function $F(z_t)$) for speed of transition $\theta = 7$ and two threshold values c - for the nominal short-term rate (graph (a)) and the real short-term rate (graph (b)) in the euro area, which we use in our baseline estimations in Section 5. The corresponding interest rates are depicted on the same graphs. For the euro area, the threshold value c is equal 0% in case of the nominal short-term rate and -1.15% for the real short-term rate. For individual euro area countries, the threshold value for the nominal short-term rate is the same as for the euro area aggregate, while thresholds for the real short-term rate vary across countries between -1.5% (Spain and the Netherlands) and -0.7% (France). We consider the constructed probabilities in Figure A1 to be plausible probability distributions of interest rate regimes from an economic point of view.

First, we experiment with the threshold values c for the nominal short-term interest rate as state variable, keeping the speed of transition θ fixed at 7. We calibrate the alternative threshold values in such a way that the low rate regime occurs in 30%, 40%, and 50% proportion of the sample. This corresponds to threshold values c of the nominal short-term rate equal to 0.25%, 0.8%, and 1.5%, respectively. Our highest calibrated threshold of 1.5% is close to the one used by Claessens et al. (2018), who classify a country as being in a 'low' rate environment when

[15] The testing procedure is as follows. Monetary policy shocks are separated into positive and negative series. The negative series take the values of the monetary policy shock when it is negative and 0 otherwise, while the positive series take the values of the shock when it is positive and 0 otherwise (we do not observe cases when the monetary policy shock is equal 0). Each shock series is then used separately for the STLPs estimation. For comparability, we construct impulse responses to a one standard deviation decrease in the positive or negative shock series.

its three-month nominal interest rate is below or equal to 1.25%. In our sample for the euro area over the period 1999q2-2019q1 this occurs in around 45% of observations. Thus, using the threshold value of 1.5% with half of the observations for the short-term rate in our sample below 1.5%, we identify the low rate regime similarly as in other studies.

We estimate impulse responses of investments and savings for alternative threshold values c in the smooth transition function, next to the baseline value of 0% for the nominal short-term interest rate (see Table A2 in the Appendix). The results for the low rate regime are more sensitive to changes in values of c than the results for the normal rate regime, but largely in line with the main findings. The responses for investments and savings become smaller in magnitude as we increase the threshold, although the sign of responses does not change. Raising the threshold implies that the low rate regime covers a longer period in the sample. Thereby, it serves as a robustness check for the impact of changing the relative length of regimes on the response to monetary policy shocks.[16] While this does not change the sample size, the effect on the standard errors of the pointwise coefficient estimates of the impulse response is similar to increased sample uncertainty.[17] Nevertheless, these modifications do not alter our conclusions.

Next, we probe the robustness of our results to using different values of parameter θ, which captures the speed of transition between the regimes. In the baseline specification θ is set to 7. As alternatives we set θ to 3 or to 10. The higher the value of θ, the more binary are regime probabilities and the faster is the transition from one regime to the other. Sensitivity to different values of θ is tested with the nominal short-term interest rate as state variable, keeping the threshold value c fixed at 0% (see Table A3 in the Appendix). The impulse responses in the normal rate regime are very similar to the baseline model for different speeds of transition, while the responses in the low rate regime are somewhat larger in absolute value when the

[16] Note that this is not equivalent to testing sensitivity of responses to the duration of the low rate regime. A higher threshold means that a larger proportion of the sample (including periods with relatively higher interest rates which in the baseline estimation are included in the normal rate regime) is assumed to be in the low rate regime.

[17] An alternative way to test whether the responses differ between the interest rate regimes could be to split the sample and estimate local projections impulse responses on the two subsamples. Given the relatively short time period when the low rate regime is observed in our sample, such approach may suffer from a small sample bias.

transition from the normal to the low rate regime is slower (i.e. θ =3). Overall, modifying the speed of transition does not affect our main findings.[18]

6.4 State variables in a smooth transition function

We use three alternative measures of state variable z_t in a smooth transition function, namely the long-term interest rate (10-year government bond yield), the bank lending rate, and the shadow rate. The variation in the short-term rate (the short end of the yield curve) is smaller than the variation at the medium/long-term part of the yield curve. The short-term rate is constrained by the effective lower bound, while long-term rates are affected by ECB's unconventional instruments: QE and Forward Guidance. Accounting for the whole yield curve matters for monetary policy transmission and macro effects. This motivates using the long-term rate as a state variable in sensitivity analysis. The lending rate captures bank lending conditions for firms and households, which could also matter for transmission in different regimes. Finally, using the shadow rate as a state variable accounts for effects of non-standard monetary policy measures such as QE. The threshold value c for the interest rates is calibrated so that the low rate regime occurs in 20% of the sample, similar to calibration used for the short-term rate. For the euro area this threshold is equal to 1.45% for the long-term rate, 2% for the lending rate, and -1.6% for the shadow rate. These thresholds (except for shadow rate) vary across individual euro area countries. The speed of transition θ is set at 7 as in the baseline specification.

Figure A1 in the Appendix shows the probability of being in the low or the normal rate regime for the nominal long-term rate (graph (c)), the nominal lending rate (graph (d)), and the shadow rate (graph (e)) as state variable, in the euro area. The timing of the low rate regime derived using these interest rates coincides partially with the timing of the low rate regime based on the nominal short-term rate. The probability of being in the low rate regime based on long-term or lending rates takes non-zero values after 2015q1, while this probability for the short-

[18] As another robustness exercise, we used a grid search to find an optimal combination of parameters c and θ. Making the assumption that the mean probability of being in a low rate regime for all observed interest rate realisations equals the defined percentile considered as 'low rate observations', we search for any combination of the percentile and θ that satisfies this condition. The grid search yields an optimal combination of the percentile equal to 20% (i.e, c=0 for nominal short-term rate as chosen in our baseline analysis) and θ=2. The responses from STLPs using these parameters are very similar to the baseline ones. While the results do not change much using the grid search parameters, the state probabilities become less clear. Moreover, from an economic point of view, transition probabilities are more realistic when choosing a somewhat higher value for the speed of transition θ.

term rate indicates the start of transition to the low rate regime to be a couple of years earlier. This could be due to a slower decline of long-term and lending rates over time compared to the observed dynamics for short-term rates in the euro area. The timing of the low rate regime based on the shadow rate (after 2012q1) is very similar to the timing for the short-term rate. Note that the low interest rate regime based on these two state variables (short-term rate and shadow rate) coincides with the euro area sovereign debt crisis. The latter was characterised by large debt overhangs and decline in economic activity, which possibly weakened the monetary policy effectiveness (e.g. Alpanda and Zubairy, 2019). The nonlinearity detected in our analysis may partially reflect the impact of these factors. In order to account for this, we include as alternative state variables the long-term interest rate and the lending rate. These result in a different timing of the low rate regime than for the short-term rates, by dating it after 2015q1. The difference in timing implicitly tests for sensitivity of the results to the euro area sovereign debt crisis (which evolved between 2010 and 2014), since the timing of the low rate regime after 2015q1 for long-term and lending rates does not coincide with the crisis.

The impulse responses of investment and savings for the euro area with alternative state variables are shown in Figures A11-A13 in the Appendix (results for other variables are available on request). The responses of investment to an expansionary monetary policy shock, based on the lending rate as state variable are similar to the baseline results with the short-term rate as state variable, in both regimes. For the long-term and shadow rates the responses of investment are insignificant in the low rate regime. The outcomes for savings using alternative interest rates are comparable in all cases to the baseline results. Thus, our conclusions are largely robust to the choice of state variable in the smooth transition function. This also indicates that nonlinearities of responses are not driven by the euro area sovereign debt crisis.

6.5 Other sensitivity tests

This section explores the sensitivity of the results to the choice of lags, estimation of the model in growth rates, and inclusion of additional control variables. In the Appendix we show the outcomes of most robustness checks for investments and savings as key dependent variables, using the nominal short-term rate in the smooth transition function, for the euro area (the results for other specifications and variables are available on request).

First, we re-estimate the models with two lags for the dependent variable instead of one, in order to allow for a more persistent autoregression; the results are not qualitatively affected by this modification, although the confidence intervals become somewhat wider, resulting in less significant impulse responses (see Figure A14).

Next, we estimate local projections models with all response variables, except for the output gap, included in log-differences. As growth rates of our variables are stationary, the time trend is redundant in the estimation. The impulse responses for private investment and savings growth (see Figure A15) are qualitatively similar to the ones for the baseline model in log-levels. Specifically, an expansionary monetary policy shock increases private investment growth in the euro area in the normal rate regime by up to 2 percentage points (p.p.), while it reduces the investment growth in the low rate regime by -2 p.p. at the trough, for about 2 years. The responses of savings growth exhibit the opposite dynamics: savings growth drops in the normal rate regime but increases by 5 p.p. at the peak in the low rate regime. These findings are in line with theory and suggest that the existence of the macroeconomic reversal rate is evident both for volumes as well as growth rates of macroeconomic variables.

Further, we experiment with the lag length for the monetary policy shock. In the baseline model it is included contemporaneously. As a sensitivity check, we use instead the first lag of the shock to account for possible delays in the monetary policy transmission. The main findings are not affected by this modification (see Figure A16). One difference is that in the linear model the savings do not respond to the one-period lagged shock significantly. The results also hold when we include one or two lags of the monetary policy shock as control variables.

We also include other control variables, next to the lagged dependent variable, to check the robustness of our main findings. Specifically, we add financial wealth of households, the real house price and real stock price (all in log-levels) to control for wealth effects (similar to Goodhart and Hofmann, 2005) as well as the services to GDP ratio (in %) to proxy for the increased share of the service sector in the economy. Since services are less capital intensive, increased importance of this sector might have reduced the interest rate sensitivity of aggregate demand. These controls could weaken the direct effect of monetary policy shocks on the response variable if the effect runs through other transmission channels than the interest rate.

We find that the impulse responses in the models including financial wealth or asset prices remain largely unchanged, both in terms of the sign and the magnitude of response (see Figures A17-A19). Adding the house price as control variable makes the response of savings less significant in the linear model and in the low rate regime but does not lead to a major change in the outcomes. Neither does the inclusion of the services ratio affect the baseline results (see Figure A20); this holds for all dependent variables and interest rate measures in a smooth transition function. Overall, the main conclusions remain broadly unchanged. Amongst others this indicates that the results in the state-dependent model are not dominated by episodes of financial crises (captured by asset prices) but driven mainly by the interest rate regime.

6.6 GDP growth as state variable

Our findings suggest that there is a reversal in the behaviour of some macroeconomic variables in a low interest rate environment, when further monetary policy stimulus seems to be less effective. An alternative explanation could be that monetary easing is less powerful when the economy is weak. Since a weak state of the economy often coincides with a low interest rate, it is important to disentangle these two conditioning factors. Therefore, as an additional robustness exercise we check whether our results are not confounded by capturing business cycles rather than interest rate regimes.

For this purpose, in the smooth transition function we use a four-quarter moving average of real GDP growth as a state variable capturing economic activity and business cycle fluctuations. For consistency and in line with the literature, we define the lowest 20% of the state variable as a threshold below which the business cycle is considered to be in a recession. Consequently, we distinguish two regimes: expansion and recession. Figure A21 in the Appendix depicts the resulting probabilities where close to 1 (0) implies a high probability of being in a recession (expansion). Figure A22 in the Appendix shows the impulse responses of investments, savings, consumption and the output gap to one standard deviation expansionary monetary policy shock in the euro area in the linear model (second column), in an expansion (third column), and in a recession (fourth column).

We observe very different patterns in responses under economic expansion and recession regimes compared to the results for interest rate regimes. Specifically, the impulse responses of all four macroeconomic variables in a recession have the opposite sign compared to the corresponding responses in the low interest rate regime. In recessions, an expansionary monetary policy shock increases investment, consumption, and the output gap in the euro area, while savings decrease after the shock. The responses are insignificant in expansions. Thus, the responses in recessions are in line with expectations, while macroeconomic variables do not seem to react to monetary policy easing during expansions. Based on this exercise we can conclude that our main findings for the low interest rate regime do not coincide with economic recession. That is, macroeconomic variables experience a reversal in their behaviour in a low interest rate environment, which does not necessarily occur in a weak state of the economy.

7. Conclusion

This paper examines nonlinearities in the reaction of spending and saving behaviour to monetary policy shocks. We employ smooth-transition local projections to estimate the impulse responses of different aggregate demand components to an expansionary monetary policy shock in the euro area and its five largest countries over the period 1999q2-2019q1 under two distinct regimes: normal and low interest rate. Our results indicate that the monetary policy transmission mechanism is different across the two regimes and the macroeconomic aggregates can respond to monetary policy shocks in an opposite way. The analysis provides evidence for the existence of a macroeconomic reversal rate, related to the income effects becoming stronger relative to the substitution effects in a low interest rate regime.

Following an expansionary monetary policy shock, private consumption, investment spending, and the output gap significantly increase in the normal interest rate regime. In contrast, in the low rate regime the impulse responses of these variables reverse signs, becoming negative and significant in most cases. This suggests that the substitution effects become weaker relative to the income effects in a low interest rate environment.

The impulse responses of gross household savings support the evidence for stronger income effects in the low rate regime. While savings volume declines after an expansionary monetary policy shock in the normal rate regime, it increases in the low rate regime. This indicates that in a low interest rate environment further monetary easing raises savings, which reflects that the income effect becomes stronger relative to the substitution effect.

Our findings show that expansionary monetary policy becomes less effective in a persistently low interest rate environment. Further monetary policy easing in such a regime could be less powerful in stimulating the real economy and boosting aggregate demand. In fact, it may even be counterproductive, by raising household savings due to negative income effects.

The existence of such nonlinearities implies that the effectiveness of monetary policy may be limited in certain macroeconomic conditions. The persistence of low interest rate levels is a likely determinant of the interest rate sensitivity of aggregate demand. The longer the interest rate remains low, the higher the likelihood of a change in the behaviour of economic agents and their expectations. Under such conditions, it is increasingly likely that income effects dominate substitution effects, thereby limiting the effectiveness of monetary policy.

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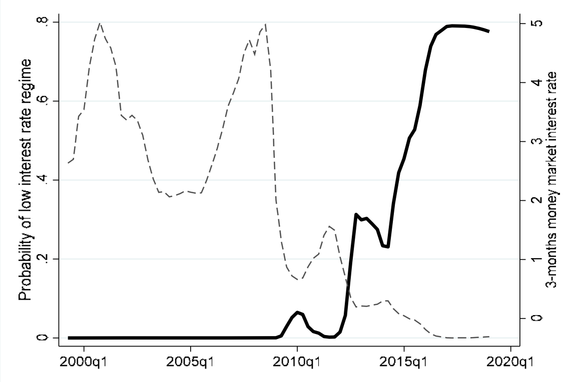
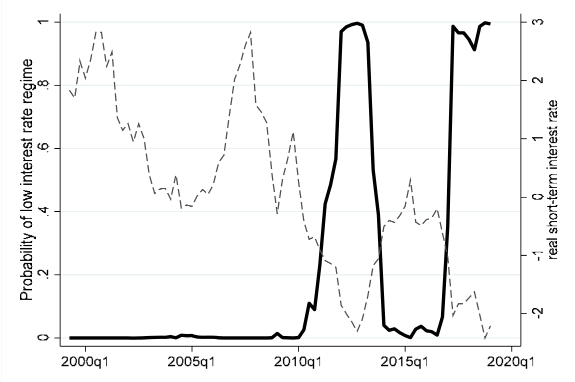
Appendix

Figure A1. Probability of being in low interest rate regime ($F(z_t) = 1$) or normal interest rate regime ($F(z_t) = 0$) based on smooth transition function $F(z_t)$, euro area

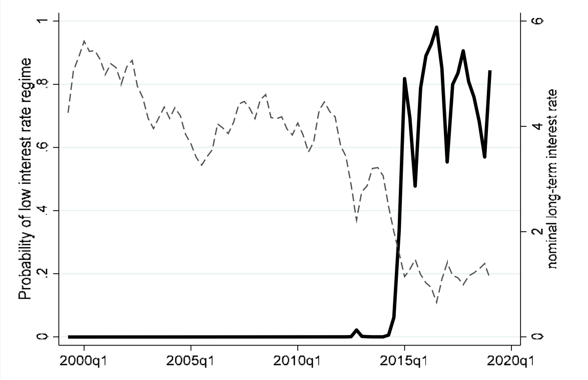
a) state variable: nominal short-term rate, c = 0, θ = 7



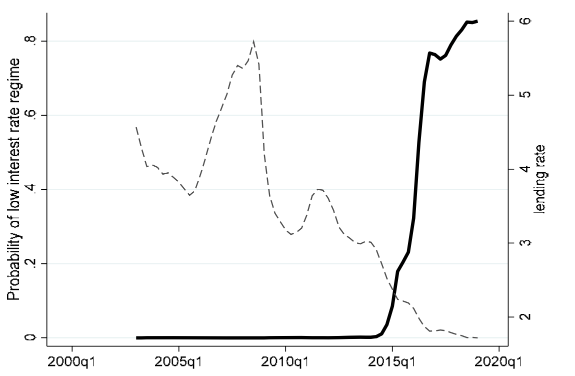
b) state variable: real short-term rate, c = -1.15, θ = 7



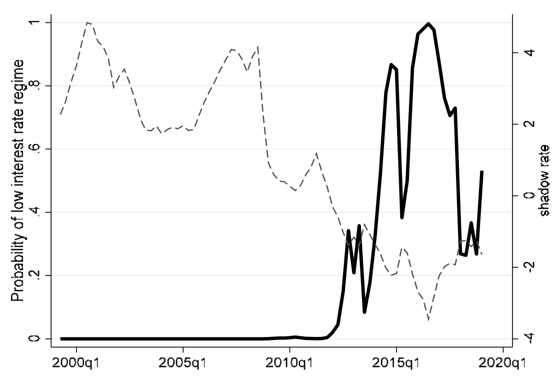
c) nominal long-term interest rate, c = 1.45, θ = 7



d) nominal lending interest rate, c = 2, θ = 7



e) shadow interest rate, c = -1.6, θ = 7

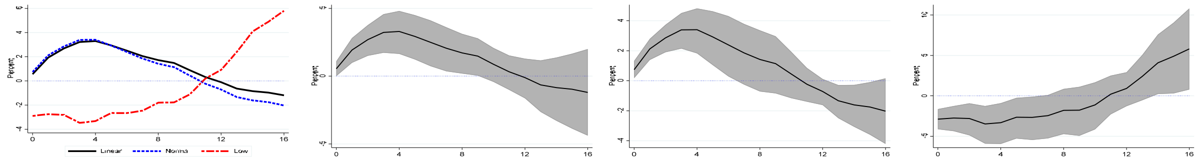


Notes: The graphs plot the probability of being in the low interest rate regime (black solid line, left y-axis) together with the corresponding interest rate used as state variable in the smooth transition function (grey dashed line, right y-axis). The proportion of the sample in the low interest rate regime is set to 20%.

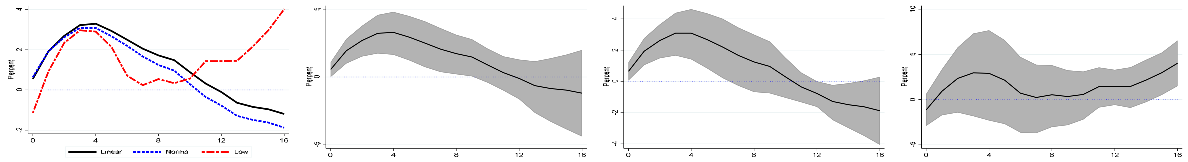
Figure A2. Impulse responses of y_{t+h} to 1 st. dev. expansionary monetary policy shock, DE

a) Capital goods investment volume (c = 0, nominal short-term interest rate)

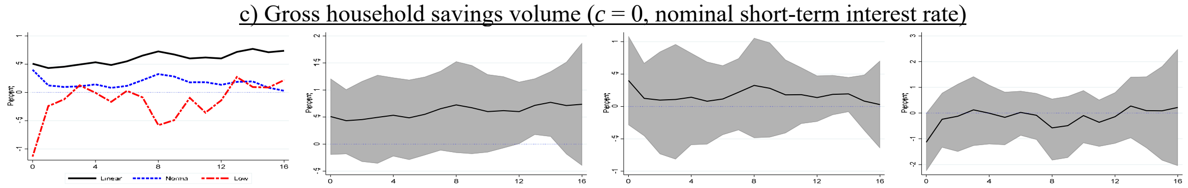
All responses *Linear model* *Normal rate regime* *Low rate regime*



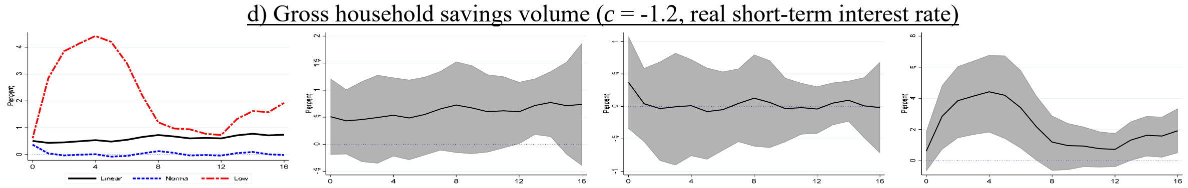
b) Capital goods investment volume (c = -1.2, real short-term interest rate)



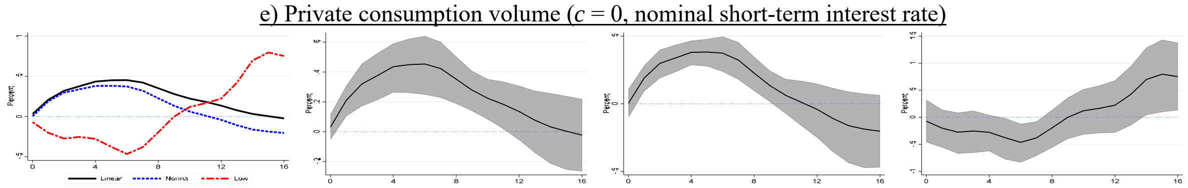
c) Gross household savings volume (c = 0, nominal short-term interest rate)



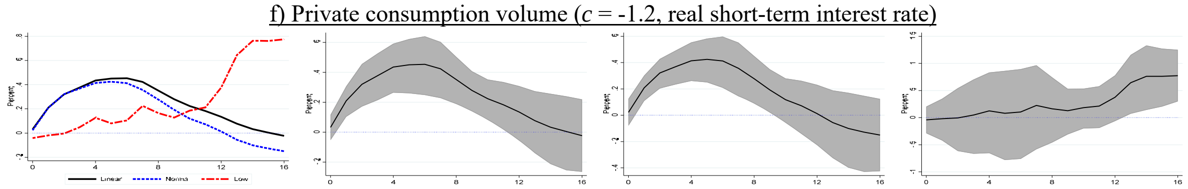
d) Gross household savings volume (c = -1.2, real short-term interest rate)



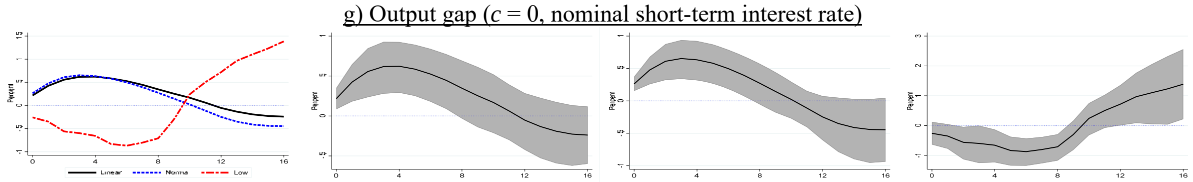
e) Private consumption volume (c = 0, nominal short-term interest rate)



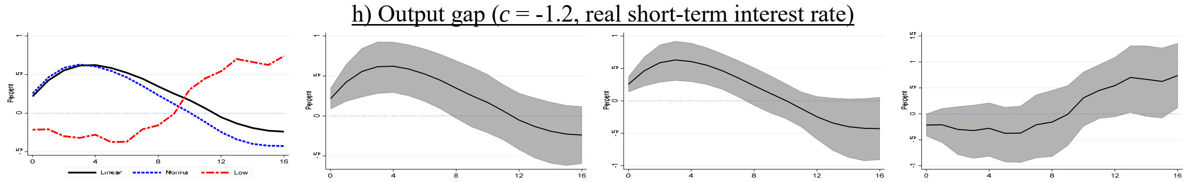
f) Private consumption volume (c = -1.2, real short-term interest rate)



g) Output gap (c = 0, nominal short-term interest rate)

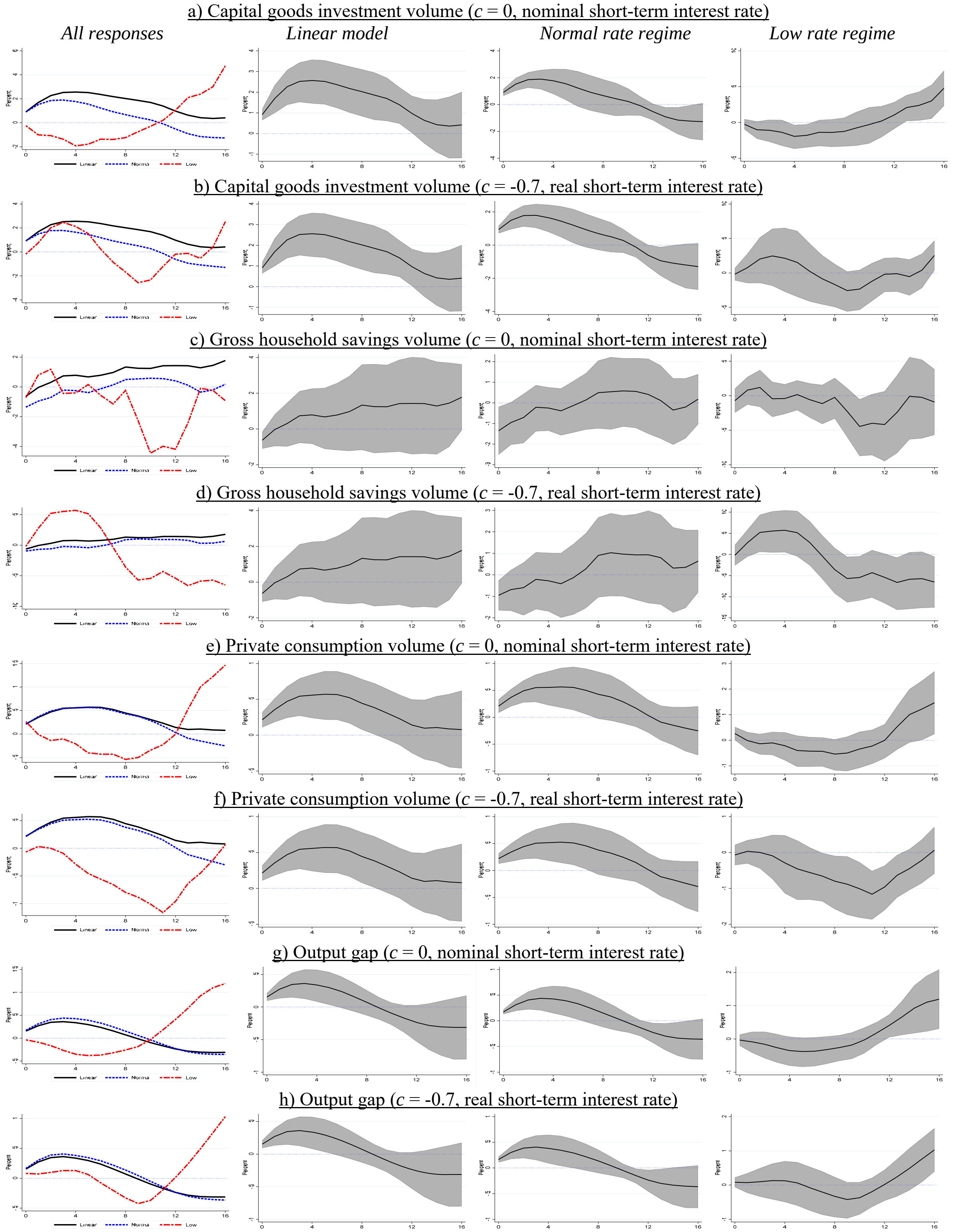


h) Output gap (c = -1.2, real short-term interest rate)



Notes: The figure plots impulse responses of investment, savings, consumption (all in log-levels), and output gap to 1 st. dev. expansionary monetary policy shock. In the first column, solid black line shows the response in the linear model, blue dashed line - in normal rate regime, and red dash-dotted line - in low rate regime. The second, third, and fourth columns show responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around responses (shaded area).

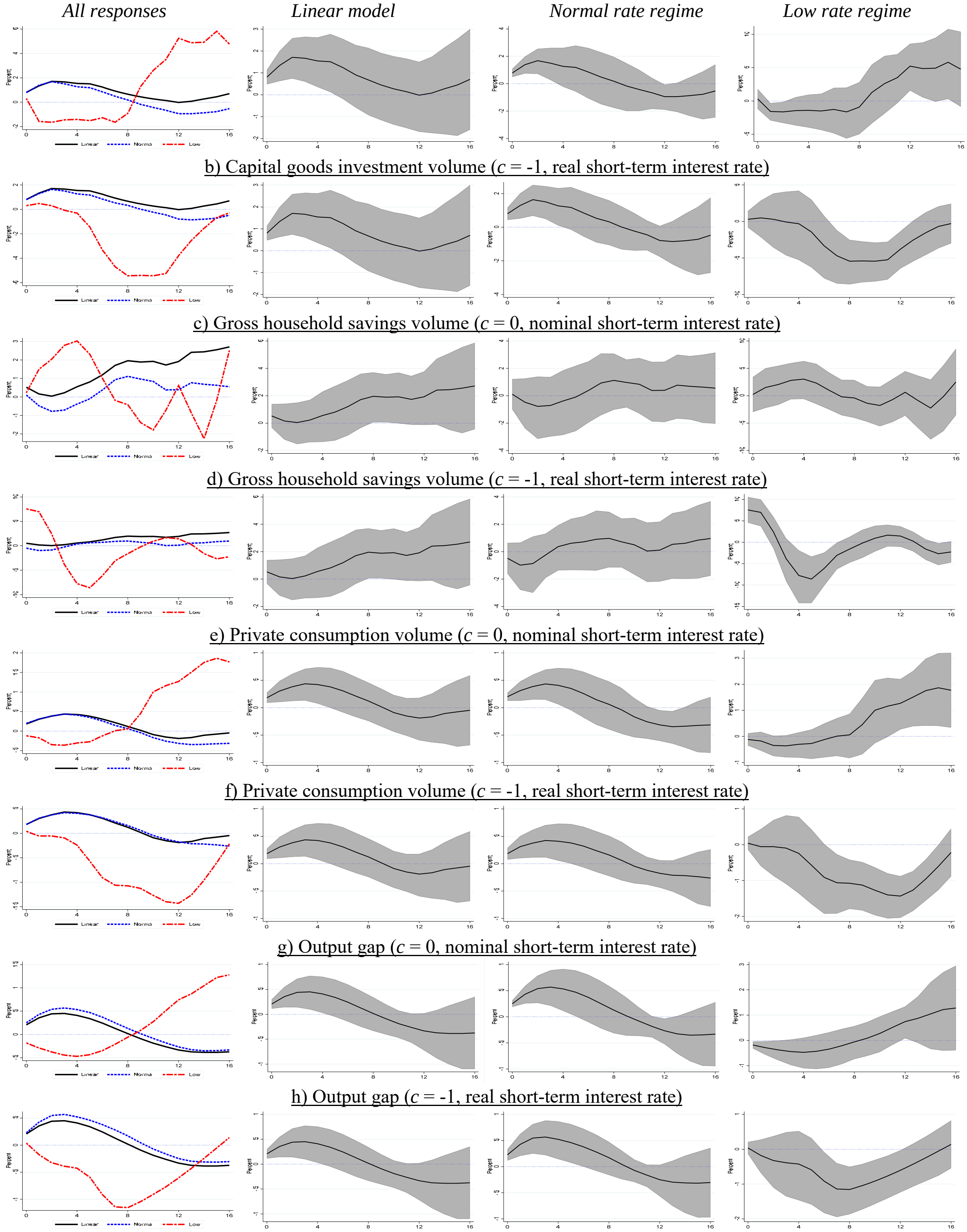
Figure A3. Impulse responses of y_{t+h} to 1 st. dev. expansionary monetary policy shock, FR



Notes: The figure plots impulse responses of investment, savings, consumption (all in log-levels), and output gap to 1 st. dev. expansionary monetary policy shock. In the first column, solid black line shows the response in the linear model, blue dashed line - in normal rate regime, and red dash-dotted line - in low rate regime. The second, third, and fourth columns show responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around responses (shaded area).

Figure A4. Impulse responses of y_{t+h} to 1 st. dev. contractionary monetary policy shock, IT

a) Capital goods investment volume (c = 0, nominal short-term interest rate)

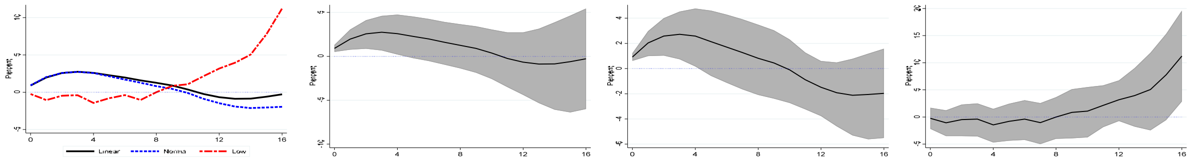


Notes: The figure plots impulse responses of investment, savings, consumption (all in log-levels), and output gap to 1 st. dev. expansionary monetary policy shock. In the first column, solid black line shows the response in the linear model, blue dashed line - in normal rate regime, and red dash-dotted line - in low rate regime. The second, third, and fourth columns show responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around responses (shaded area).

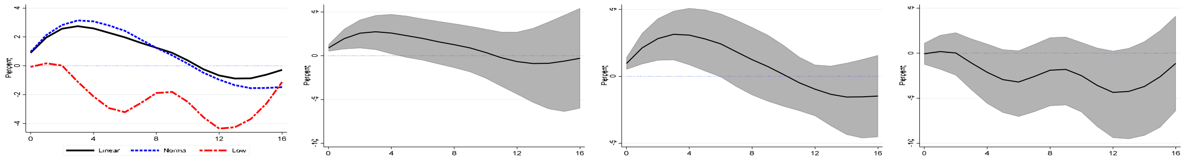
Figure A5. Impulse responses of y_{t+h} to 1 st. dev. contractionary monetary policy shock, ES

a) Capital goods investment volume (c = 0, nominal short-term interest rate)

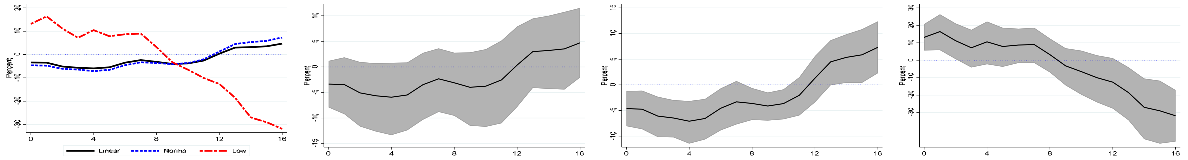
All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



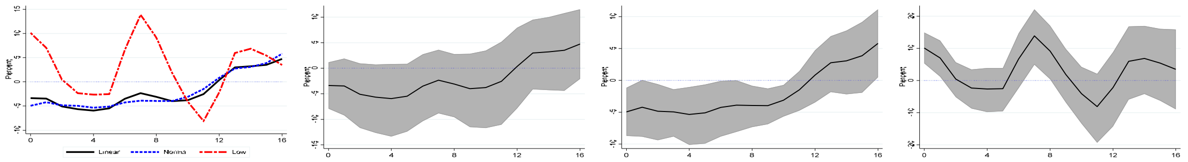
b) Capital goods investment volume (c = -1.5, real short-term interest rate)



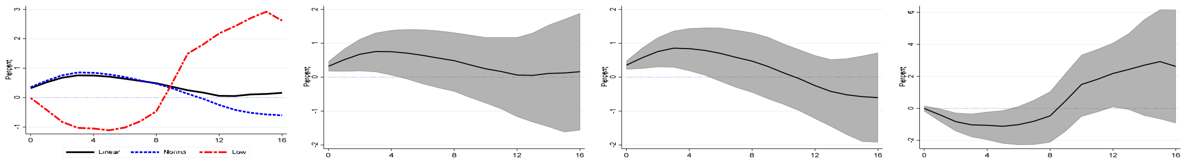
c) Gross household savings volume (c = 0, nominal short-term interest rate)



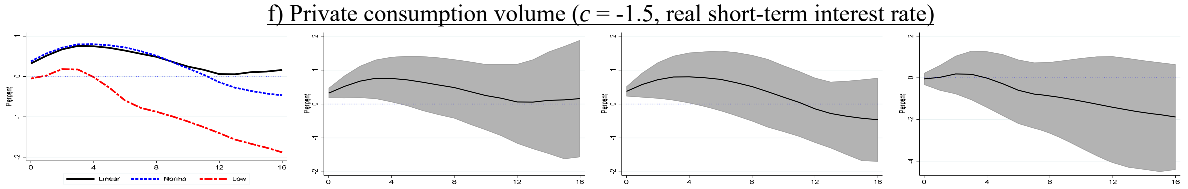
d) Gross household savings volume (c = -1.5, real short-term interest rate)



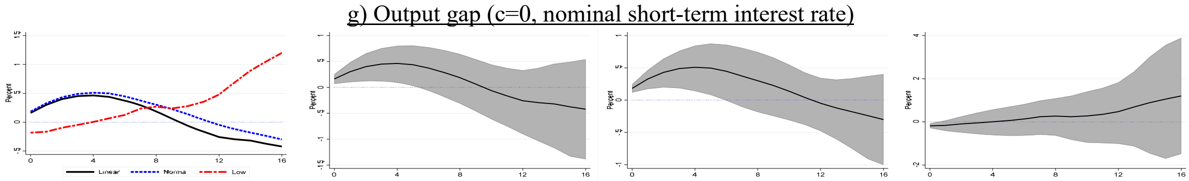
e) Private consumption volume (c = 0, nominal short-term interest rate)



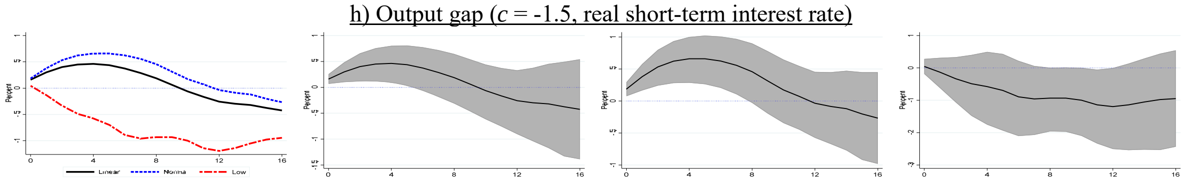
f) Private consumption volume (c = -1.5, real short-term interest rate)



g) Output gap (c=0, nominal short-term interest rate)

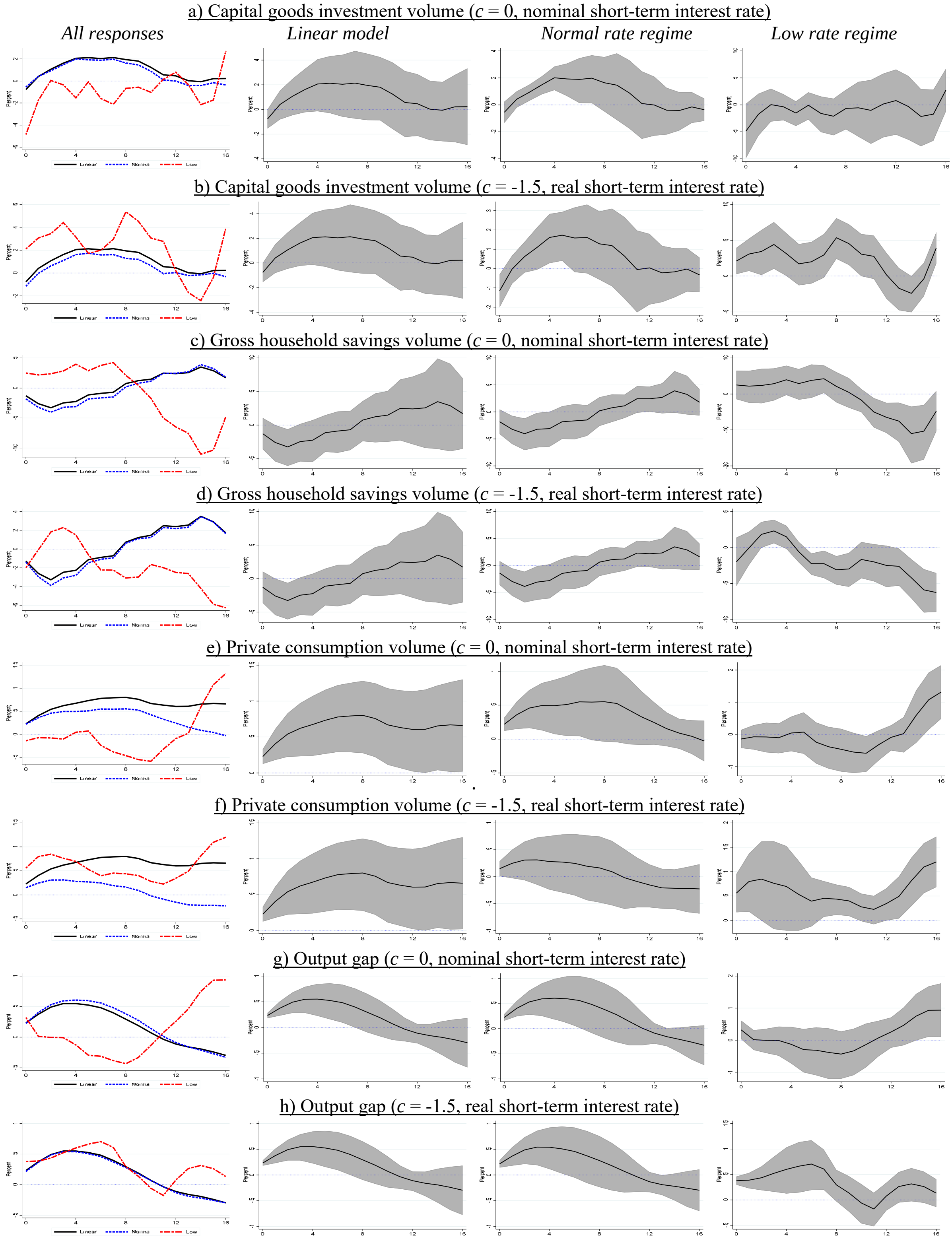


h) Output gap (c = -1.5, real short-term interest rate)



Notes: The figure plots impulse responses of investment, savings, consumption (all in log-levels), and output gap to 1 st. dev. expansionary monetary policy shock. In the first column, solid black line shows the response in the linear model, blue dashed line - in normal rate regime, and red dash-dotted line - in low rate regime. The second, third, and fourth columns show responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around responses (shaded area).

Figure A6. Impulse responses of y_{t+h} to 1 st. dev. contractionary monetary policy shock, NL

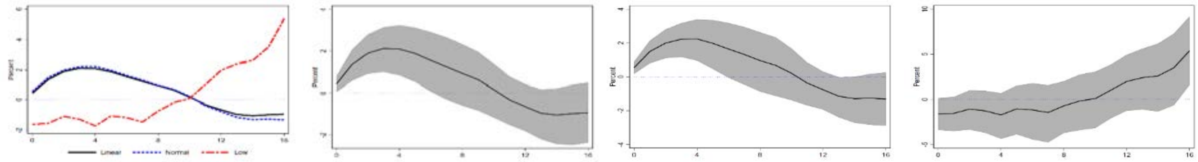


Notes: The figure plots impulse responses of investment, savings, consumption (all in log-levels), and output gap to 1 st. dev. expansionary monetary policy shock. In the first column, solid black line shows the response in the linear model, blue dashed line - in normal rate regime, and red dash-dotted line - in low rate regime. The second, third, and fourth columns show responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around responses (shaded area).

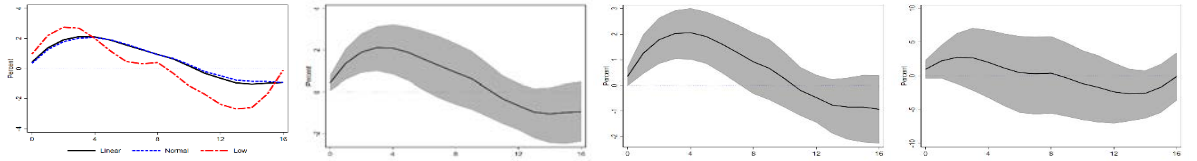
Figure A7. Impulse responses of y_{t+h} to 1 st. dev. expansionary monetary policy shock, panel data

a) Capital goods investment volume (c = 0, nominal short-term interest rate)

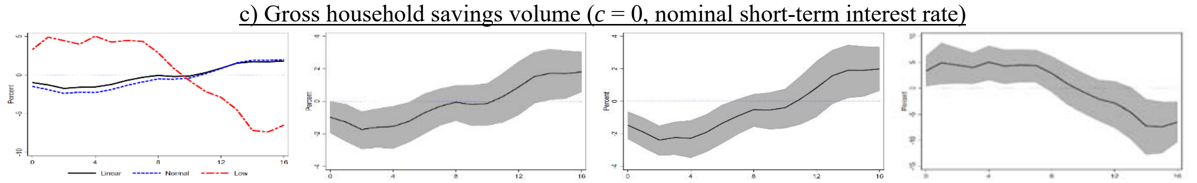
All responses	*Linear model*	*Normal rate regime*	*Low rate regime*



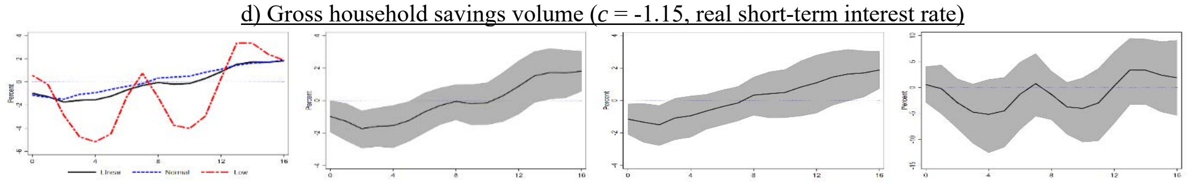
b) Capital goods investment volume (c = -1.15, real short-term interest rate)



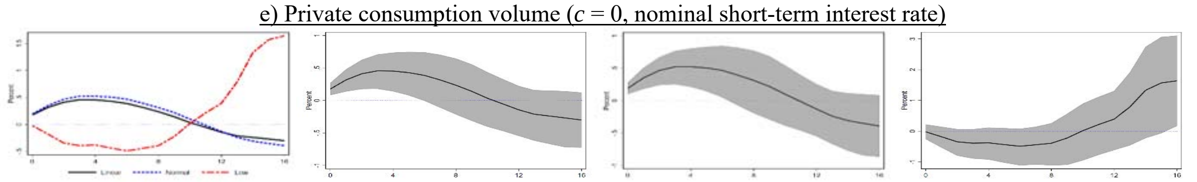
c) Gross household savings volume (c = 0, nominal short-term interest rate)



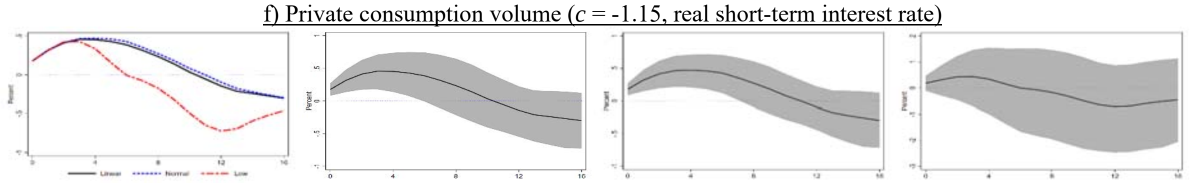
d) Gross household savings volume (c = -1.15, real short-term interest rate)



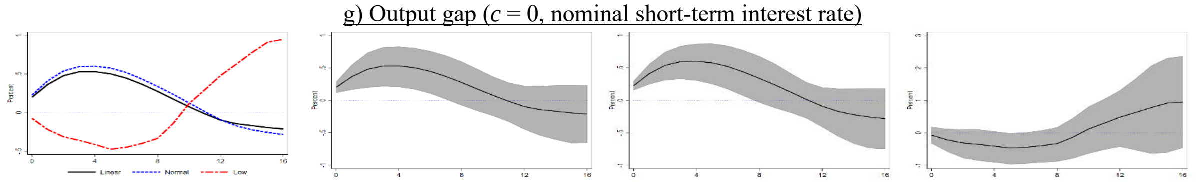
e) Private consumption volume (c = 0, nominal short-term interest rate)



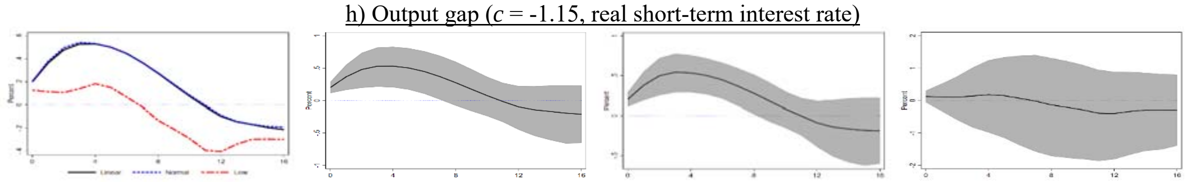
f) Private consumption volume (c = -1.15, real short-term interest rate)



g) Output gap (c = 0, nominal short-term interest rate)

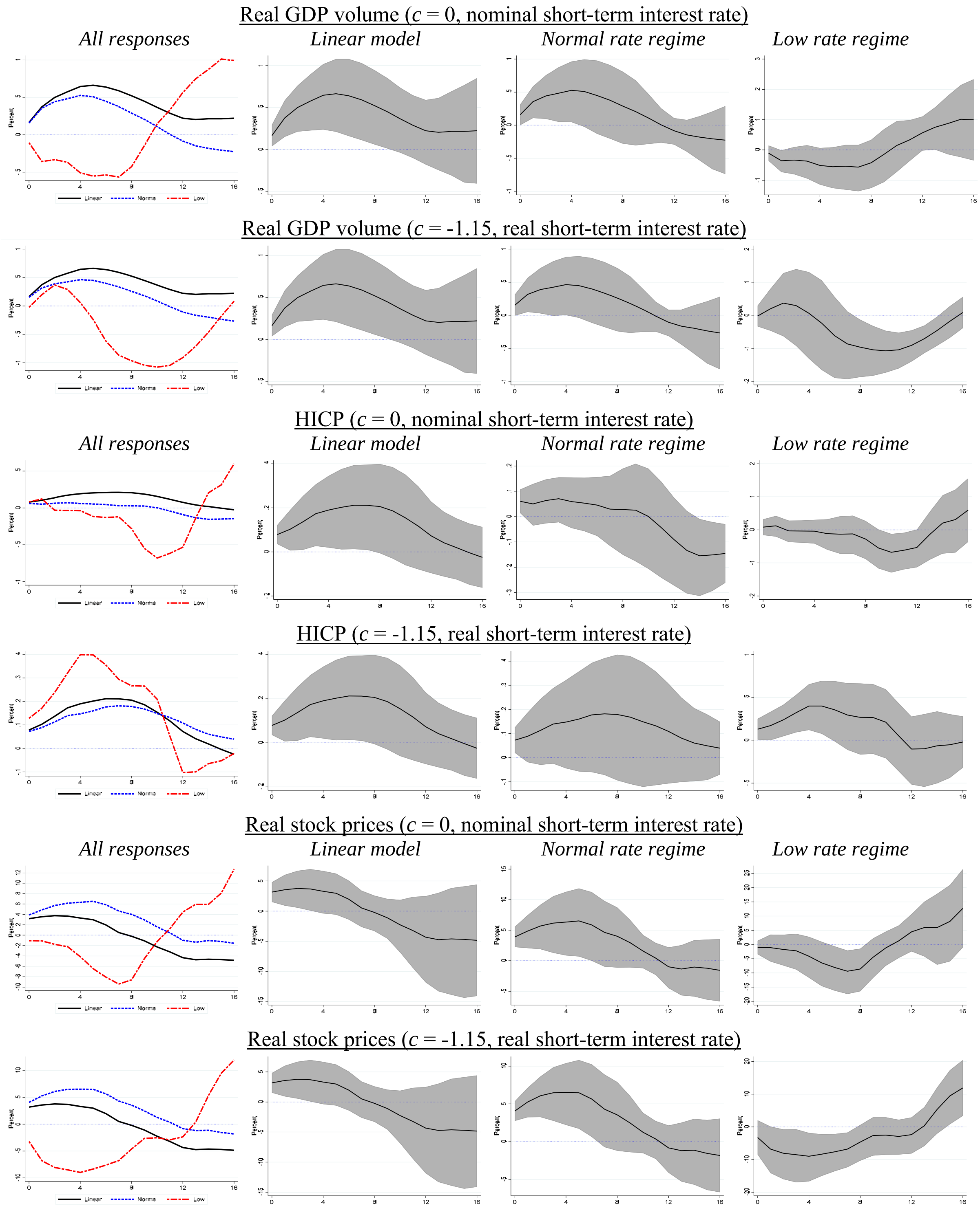


h) Output gap (c = -1.15, real short-term interest rate)



Notes: The figure plots impulse responses of investment, savings, consumption (all in log-levels), and output gap to 1 st. dev. expansionary monetary policy shock, based on a panel estimation for 5 EA countries (DE, FR, ES, IT, NL). In the first column, solid black line shows the response in the linear model, blue dashed line - in normal rate regime, and red dash-dotted line - in low rate regime. The second, third, and fourth columns show responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around responses (shaded area).

Figure A8. Impulse responses of y_{t+h} to 1 st.dev. expansionary monetary policy shock, euro area

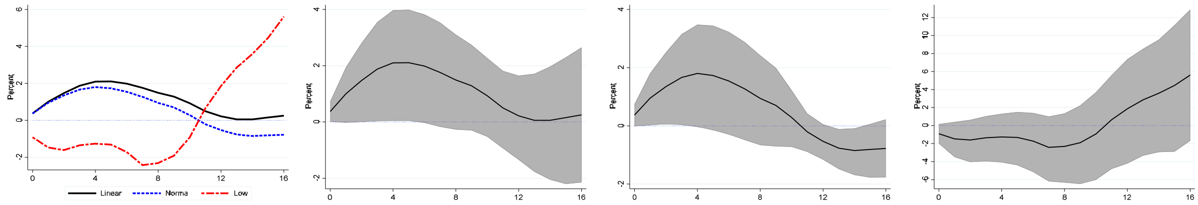


Notes: The figure plots smoothed impulse responses of real GDP volume, HICP, and real stock price (all in log-levels) to 1 st. dev. expansionary monetary policy shock. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal interest rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

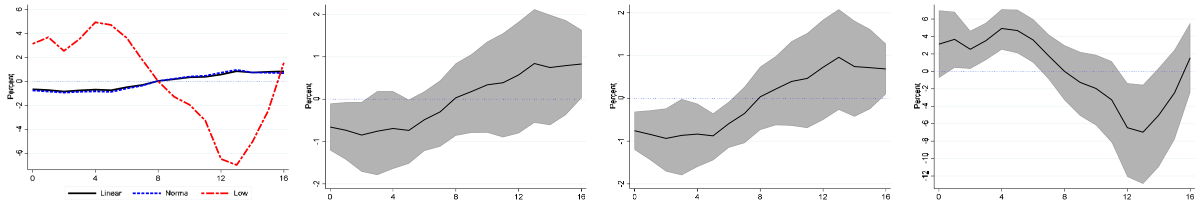
Figure A9. Impulse responses of investments and savings to an expansionary shock, euro area, robustness check: “poor man’s” monetary policy shock from JK2020

Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*



Gross household savings volume (c = 0, nominal short-term interest rate)

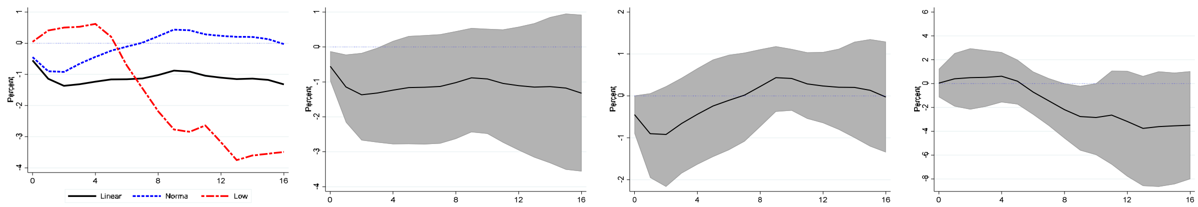


Notes: The figure plots smoothed impulse responses of capital goods investment and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock (poor man’s sign restrictions identification) in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

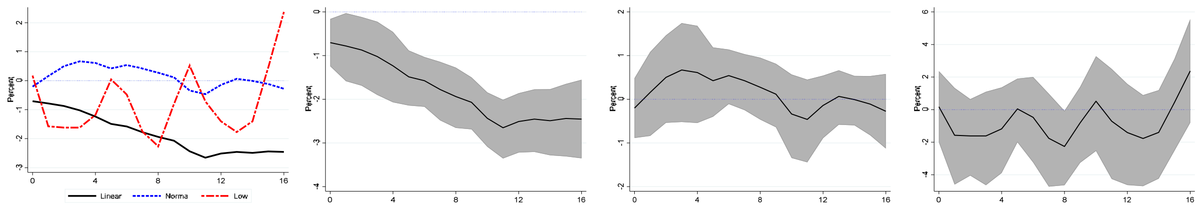
Figure A10. Impulse responses of investments and savings to an expansionary shock, euro area, robustness check: central bank information shock from JK2020

Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*

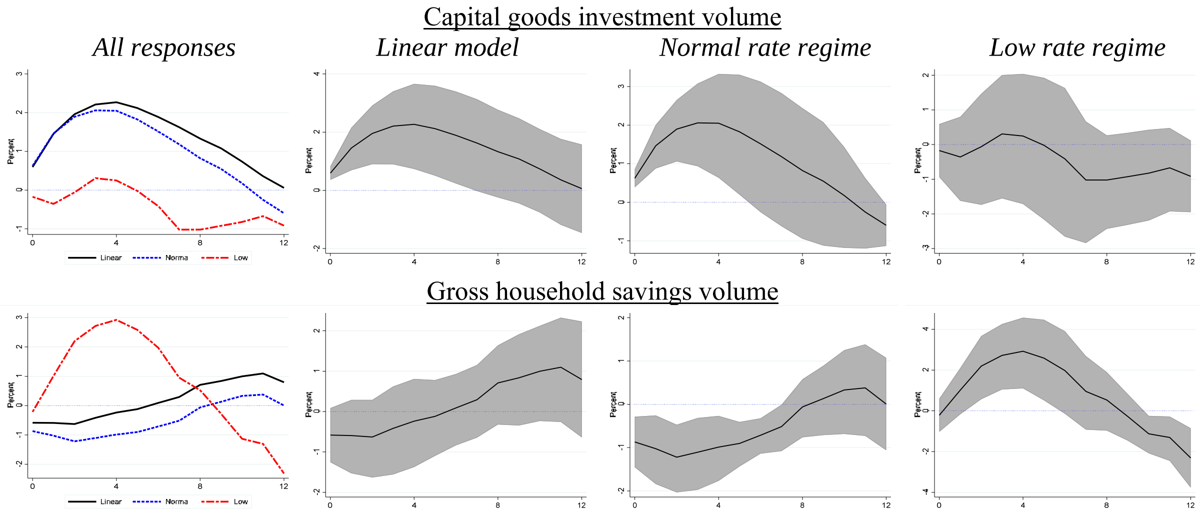


Gross household savings volume (c = 0, nominal short-term interest rate)



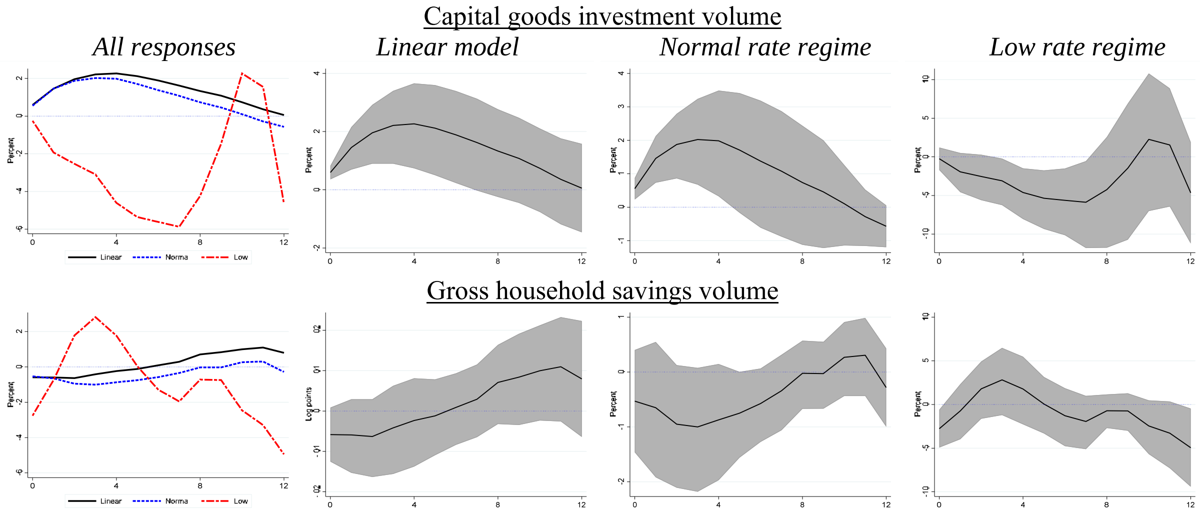
Notes: The figure plots smoothed impulse responses of capital goods investment and gross household savings (all in log-levels) to a 1 st. dev. expansionary central bank information shock (baseline sign restrictions identification) in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A11. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: state variable - nominal long-term interest rate, *c* = 1.45



Notes: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area). Given the extremely large magnitude of responses for investments after 12 quarters in the low rate regime defined by the long-term rate, the responses are displayed in the horizon $h = 12$ for a better graph visibility.

Figure A12. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: state variable – nominal lending rate, *c* = 2

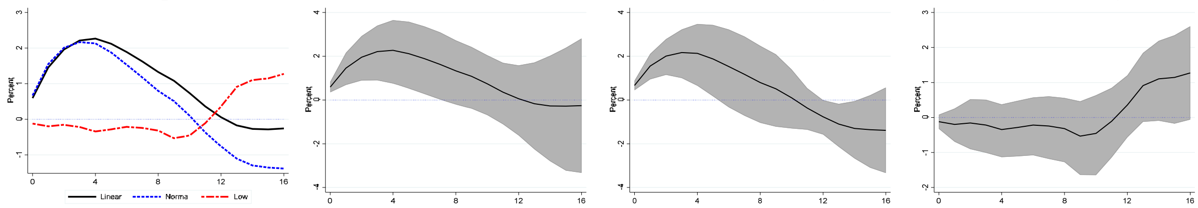


Notes: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area). Given the extremely large magnitude of responses for investment after 12 quarters in the low rate regime defined by the lending rate, the responses are displayed in the horizon $h = 12$ for a better graph visibility.

Figure A13. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: state variable – shadow rate, *c* = -1.6

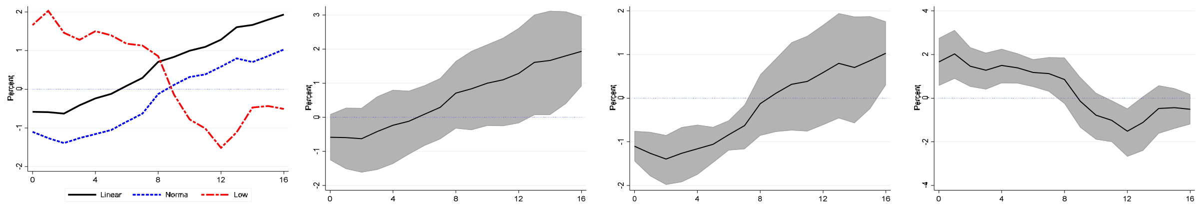
Capital goods investment volume

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



Gross household savings volume

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*

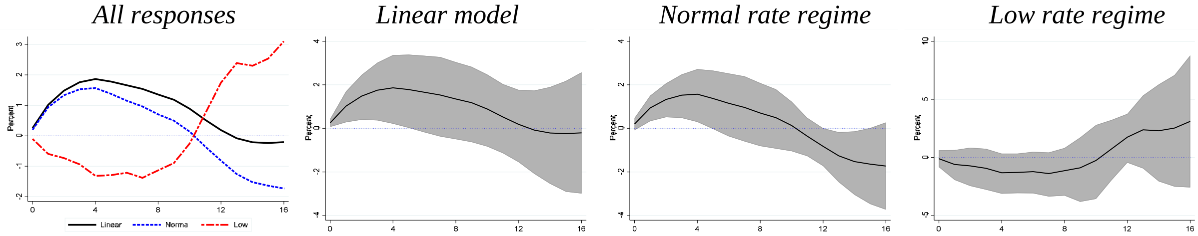


Notes: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A14. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check with two lags of dependent variable included as controls

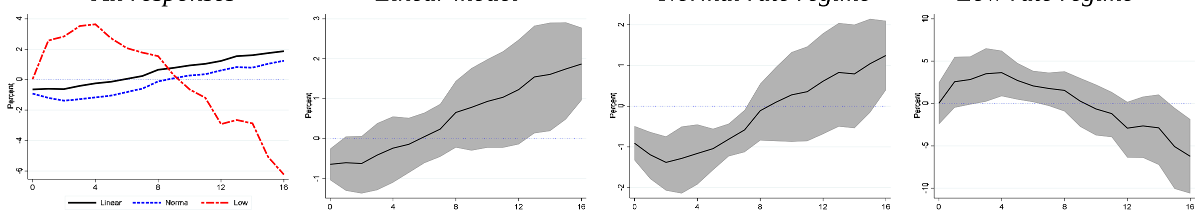
Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



Gross household savings volume (c = 0, nominal short-term interest rate)

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*

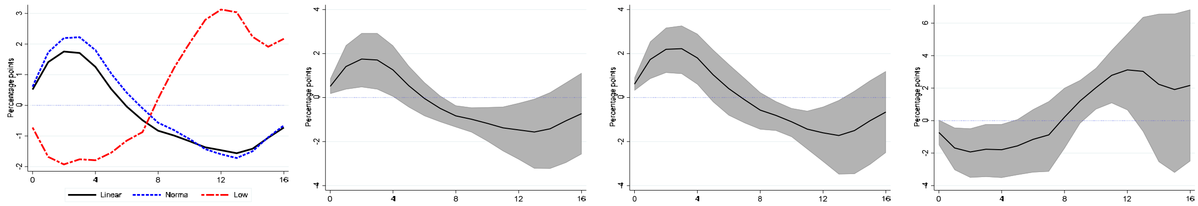


Notes: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A15. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check with dependent variables in log-differences

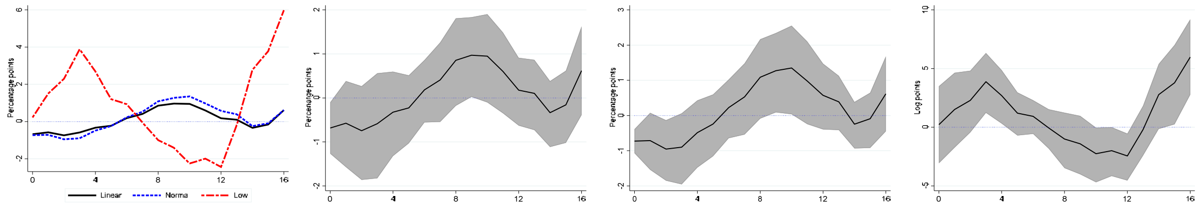
Capital goods investment growth (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*



Gross household savings growth (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*

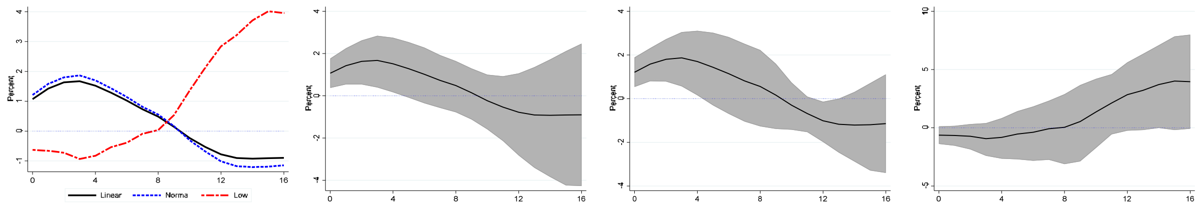


Notes: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A16. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: monetary policy shock included with first lag

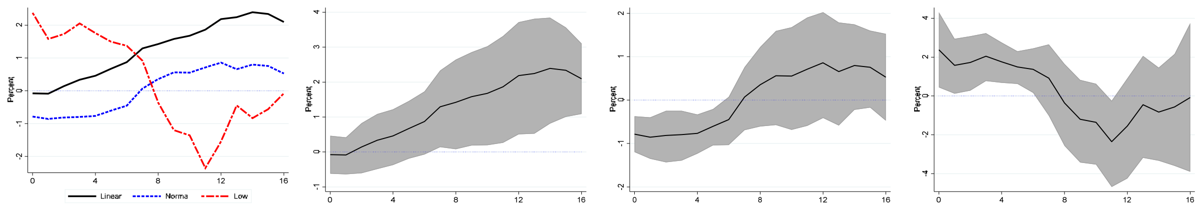
Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*



Gross household savings volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*

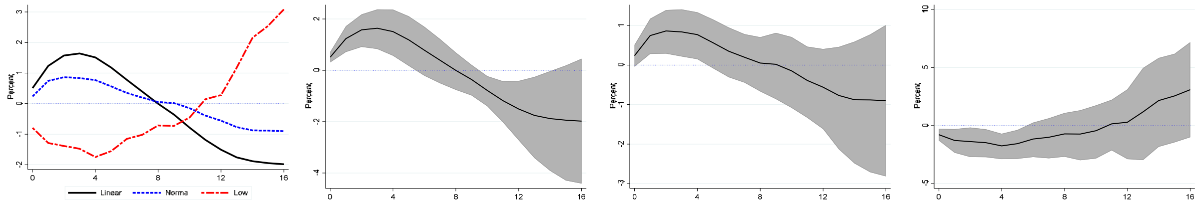


Notes: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A17. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: households' financial wealth as additional control variable

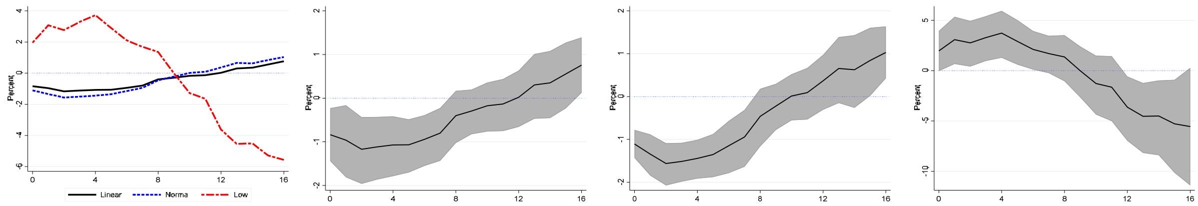
Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



Gross household savings volume (c = 0, nominal short-term interest rate)

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*

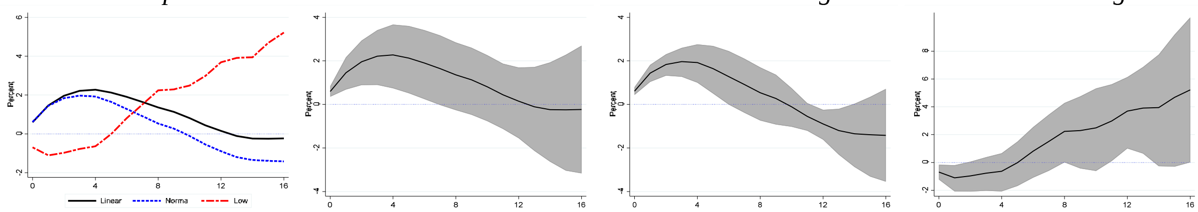


Notes: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A18. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: real house prices as additional control variable

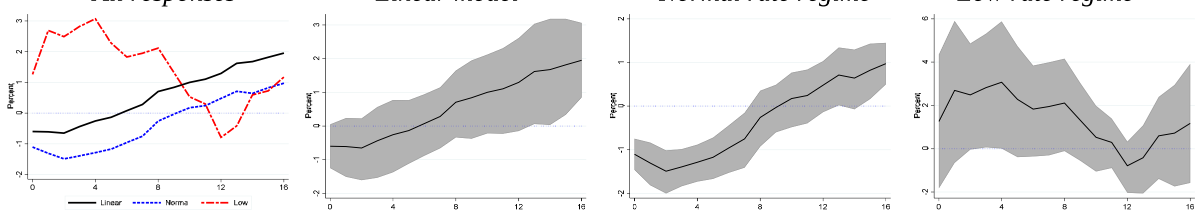
Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



Gross household savings volume (c = 0, nominal short-term interest rate)

All responses | *Linear model* | *Normal rate regime* | *Low rate regime*

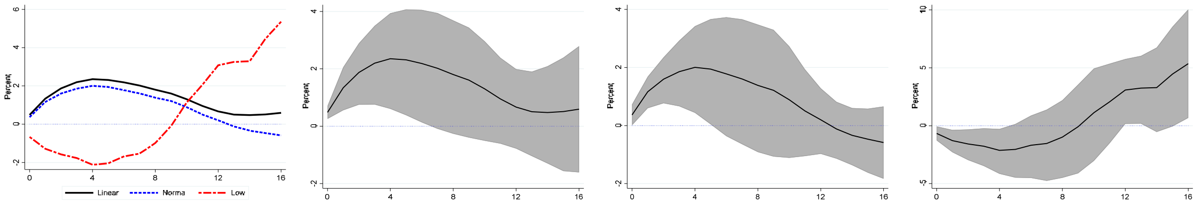


Notes: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A19. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: real stock prices as additional control variable

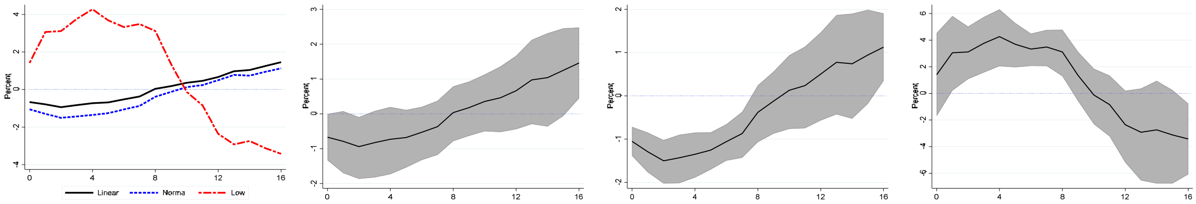
Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*



Gross household savings volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*

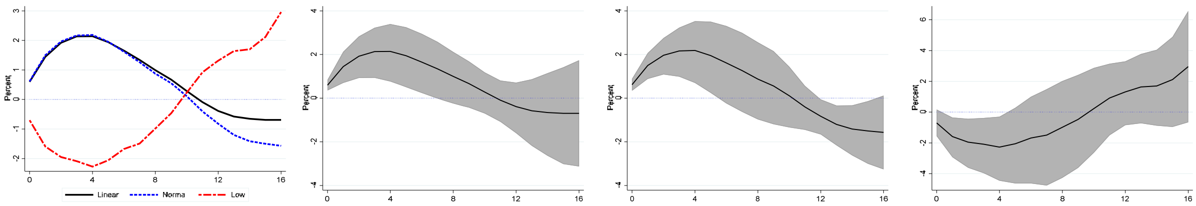


Notes: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A20. Impulse responses of investments and savings to an expansionary monetary policy shock, euro area, robustness check: services-to-GDP ratio as additional control variable

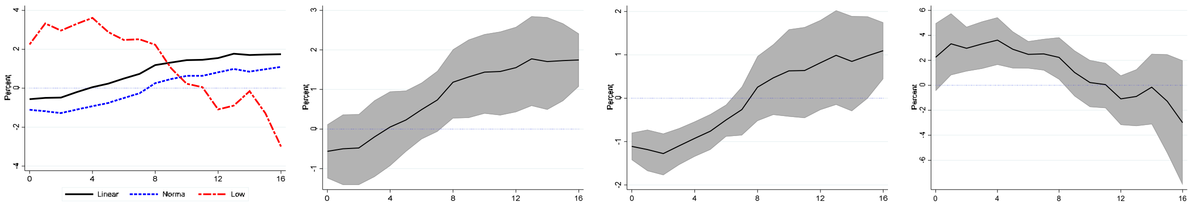
Capital goods investment volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*



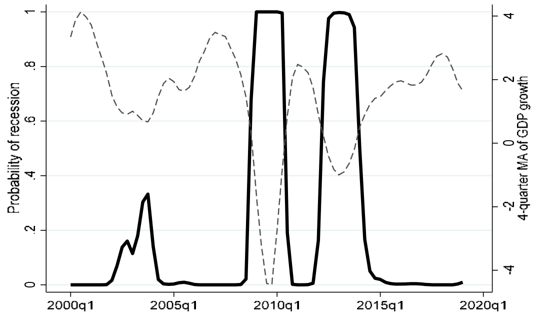
Gross household savings volume (c = 0, nominal short-term interest rate)

All responses *Linear model* *Normal rate regime* *Low rate regime*



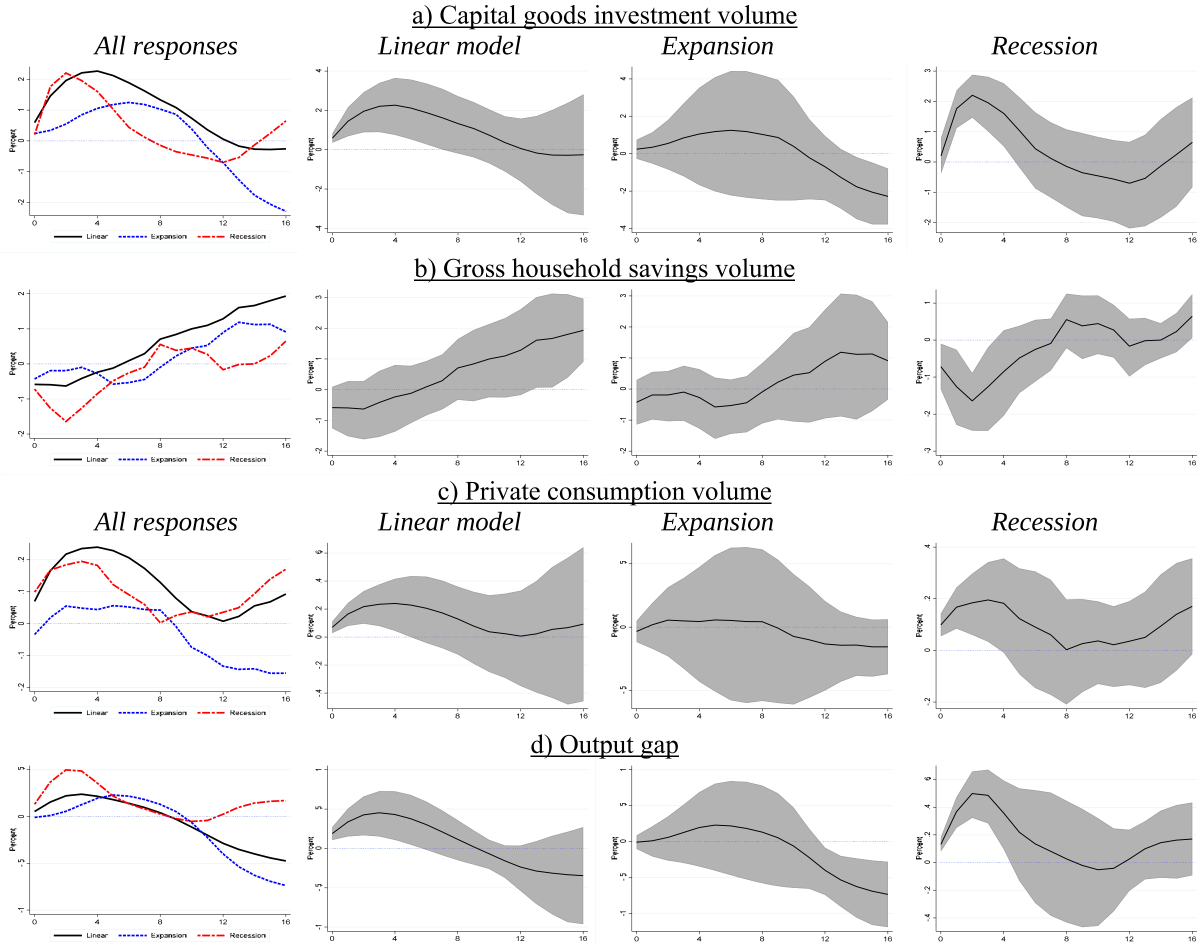
Notes: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a 1 st. dev. expansionary monetary policy shock in the euro area. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in the normal rate regime, and the red dash-dotted line - in the low rate regime. The second, third, and fourth columns show the responses in the linear model, normal, and low rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure A21. Probability of being in recession, euro area, state variable: 4-quarter MA of GDP growth, $c = 0.5$, $\theta = 7$



Notes: The graph plots the probability of being in a recession (black solid line, left y-axis) together with the corresponding four-quarter moving-average of real GDP growth rate used as state variable in the smooth transition function (grey dashed line, right y-axis). The proportion of the sample in a recession is set to 20%.

Figure A22. Impulse responses of y_{t+h} to one st. dev. expansionary monetary policy shock, euro area, state variable: 4-quarter MA of GDP growth.



Notes: The figure plots the smoothed impulse responses of capital goods investments, gross household savings, private consumption (all in log-levels) and output gap to 1 st. dev. expansionary monetary policy shock. In the first column, the solid black line shows the response in the linear model, the blue dashed line - in expansion, and the red dash-dotted line - in recession. The second, third, and fourth columns show the responses in the linear model, expansion, and recession, respectively, with a 90% confidence interval around the responses (shaded area).

Table A1. Joint Chi-squared test for significance of differences between responses, euro area

	State variable	Chi(2)-statistic	P-value
Capital goods investment volume	nominal short-term rate	74.91	0.00
	real short-term rate	30.71	0.02
Gross household savings volume	nominal short-term rate	73.97	0.00
	real short-term rate	164.57	0.00
Private consumption volume	nominal short-term rate	60.00	0.00
	real short-term rate	34.74	0.01
Output gap	nominal short-term rate	43.87	0.00
	real short-term rate	32.88	0.01

Notes: The table reports the joint Chi-squared test results for the significance of differences between the median impulse responses in the Normal and the Low interest rate regime, with a nominal (real) short-term interest rate as state variable in a smooth transition function. *P*-value <0.01, <0.05 implies the rejection of the null hypotheses of no differences between responses, on the 1% and 5% significance level, respectively.

Table A2. Impulse responses of investments and savings for different threshold values *c* of a state variable (nominal short-term interest rate) in a smooth transition function, euro area

Euro area	Baseline, *c = 0%*		*c = 0.25%*		*c = 0.8%*		*c = 1.5%*	
At horizon *h=*	Normal	Low *20% sample*	Normal	Low *30% sample*	Normal	Low *40% sample*	Normal	Low *50% sample*
Capital goods investment volume								
0	0.638 (0.152)	-0.707 (0.440)	0.639 (0.156)	-0.323 (0.240)	0.638 (0.154)	-0.026 (0.117)	0.612 (0.173)	-0.141 (0.246)
4	2.140 (0.843)	-2.299 (1.071)	2.144 (0.852)	-0.754 (0.606)	2.146 (0.867)	0.305 (0.445)	2.471 (0.825)	-0.154 (0.516)
8	0.822 (1.035)	-1.080 (1.589)	0.811 (1.028)	-0.439 (0.943)	0.758 (0.966)	0.144 (0.920)	1.227 (1.010)	-1.019 (0.577)
12	-0.758 (0.367)	1.766 (1.389)	-0.777 (0.381)	0.347 (0.867)	-0.970 (0.366)	-0.510 (0.927)	-0.646 (0.520)	-1.812 (0.751)
16	-1.423 (1.239)	4.819 (2.759)	-1.440 (1.272)	2.039 (1.325)	-1.615 (1.297)	0.427 (0.885)	-1.639 (1.109)	-0.995 (1.109)
Gross household savings volume								
0	-1.087 (0.192)	1.909 (1.855)	-1.191 (0.142)	1.475 (1.037)	-1.241 (0.165)	0.916 (0.500)	-1.186 (0.132)	0.691 (0.367)
4	-1.211 (0.432)	3.661 (1.433)	-1.315 (0.398)	2.319 (0.787)	-1.428 (0.393)	1.147 (0.478)	-1.023 (0.265)	0.476 (0.448)
8	-0.139 (0.468)	1.713 (1.230)	-0.178 (0.470)	0.890 (0.896)	-0.240 (0.584)	0.528 (0.730)	0.207 (0.645)	-0.003 (0.469)
12	0.625 (0.655)	-3.449 (1.749)	0.588 (0.612)	-2.220 (0.907)	0.520 (0.547)	-0.964 (0.406)	0.972 (0.468)	-0.859 (0.209)
16	1.063 (0.436)	-2.679 (1.443)	1.046 (0.431)	-1.174 (0.720)	1.017 (0.442)	-0.125 (0.344)	1.278 (0.384)	-0.257 (0.291)

Notes: The table reports the median responses in percent (with Newey-West standard errors in parentheses) of capital goods investments and gross household savings in the euro area to a 1 st. dev. expansionary monetary policy shock, in normal (Normal) and low interest rate regimes (Low). The speed of transition θ is fixed at *7.*

Table A3. Impulse responses of investments and savings for different values of θ in a smooth transition function, $c = 0$ for a state variable (nominal short-term interest rate), euro area

Euro area	Baseline, θ =7		θ =3		θ =10	
At horizon h=	Normal	Low	Normal	Low	Normal	Low
Capital goods investment volume						
0	0.638 (0.152)	-0.707 (0.440)	0.586 (0.169)	-0.991 (0.426)	0.632 (0.147)	-0.568 (0.492)
4	2.140 (0.843)	-2.299 (1.071)	2.134 (0.873)	-2.554 (1.348)	2.118 (0.827)	-1.991 (1.066)
8	0.822 (1.035)	-1.080 (1.589)	0.820 (1.010)	-0.898 (2.264)	0.817 (1.023)	-0.987 (1.392)
12	-0.758 (0.367)	1.766 (1.389)	-0.880 (0.371)	0.441 (1.989)	-0.746 (0.349)	2.582 (1.522)
16	-1.423 (1.239)	4.819 (2.759)	-1.650 (1.271)	3.194 (2.605)	-1.402 (1.191)	6.437 (2.857)
Gross household savings volume						
0	-1.087 (0.192)	1.909 (1.855)	-1.247 (0.141)	2. 804 (1.329)	-0.998 (0.252)	1.270 (1.902)
4	-1.211 (0.432)	3.661 (1.433)	-1.461 (0.406)	3.749 (1.194)	-1.114 (0.447)	3.343 (1.514)
8	-0.139 (0.468)	1.713 (1.230)	-0.236 (0.558)	1.129 (1.602)	-0.107 (0.467)	1.740 (1.276)
12	0.625 (0.655)	-3.449 (1.749)	0.625 (0.568)	-3.421 (1.507)	0.617 (0.660)	-2.998 (1.808)
16	1.063 (0.436)	-2.679 (1.443)	1.064 (0.437)	-2.069 (1.118)	1.067 (0.440)	-3.129 (1.826)

Notes: The table reports the median responses in percent (with Newey-West standard errors in parentheses) of capital goods investment and gross household savings in the euro area to a 1 st. dev. expansionary monetary policy shock, in normal (Normal) and low interest rate regimes (Low). The parameter c is fixed at 0.

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