Macroeconomic Reversal Rate in a Low Interest Rate Environment*

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This paper investigates how the monetary policy transmission changes once the economy is in a low interest rate environment. We estimate a nonlinear model for the euro area and a panel of 10 euro-area countries over the period 1999–2019 and allow for the effects of monetary policy shocks to be state dependent. Using smooth transition local projections (STLPs), 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 changes in the monetary policy transmission across the two interest rate regimes. Expansionary monetary policy shocks are either less effective in stimulating aggregate demand or their impact reverses the sign in a low interest rate regime.

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1. Introduction

The decade following the Global Financial Crisis (GFC) has been marked by historically low interest rates. A period of low interest rates may alter monetary policy transmission to various components of aggregate demand. It is thus important to understand whether the sensitivity of the economy to monetary policy changes is different in a low—compared with a normal—interest rate environment. A low rate environment may lead to higher savings of firms and households if negative income effects dominate substitution effects (Colciago, Samarina, and de Haan 2019). Furthermore, investments in capital goods could be discouraged due to lower marginal returns on capital (Palley 2019), or banks might reduce their lending due to compressed interest rate margins. The relevance and strength of these channels may hinder the effectiveness of expansionary monetary policy or even generate 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 counterproductive in stimulating aggregate demand.

This paper examines nonlinearities in the monetary policy transmission 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 (STLP) model for the euro area (EA, hereafter) and a panel of 10 EA countries and analyze 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, as a period of low interest rates has implications for several channels of monetary policy transmission. First, a low interest rate environment alters consumption and savings patterns through the redistribution channel and the relative strength of the substitution, wealth, and income effects. Second, it affects investments in capital goods due to diminishing returns on those assets and changes in the relative returns on financial assets. Furthermore, investments can also be reduced if banks decrease lending due to squeezed interest rate margins and downward pressure on profitability.

The substitution and income effects refer to the redistribution 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 an 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 shift the spending power of asset holders across time. The income effect is linked 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.

A low interest rate environment may affect the redistribution 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 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. 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, thereby reinforcing 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 interest rate environment, which could counterbalance the negative income effects on savings.

A low interest rate regime not only affects 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; Darracq Pariès, Kok, and Rottner 2020). At that point, a lower policy rate can lead to higher instead of lower lending rates and therefore reduce lending demand 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 aggregate demand and household savings.

There is a rich literature analyzing the transmission of monetary policy shocks and the relationship between interest rates and spending in a linear setting (see Section 2.2). However, the evidence on monetary policy transmission channels in a low rate environment remains scant. Our paper adds to the literature by considering nonlinearities in the responses of economic variables to monetary policy shocks and distinguishing two interest rate regimes.

We investigate the state dependence of monetary policy shocks using an STLP model and provide evidence on how a low interest rate environment may alter impulse responses, in particular for savings and investments. The STLP method allows the effect of monetary policy shocks on 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 the monetary policy transmission and its effectiveness in a low interest rate environment. 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, as the responses of savings and investment to monetary policy shocks differ across interest rate regimes. In the normal 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. 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. Bank lending also behaves different in a low rate regime. We find that an expansionary monetary shock leads to a decline in credit volumes and not an increase, like in a normal rate regime. Overall, our findings show that the monetary policy transmission changes in a 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 main results, while Section 6 provides several sensitivity analyses. Section 7 concludes with a summary and policy implications.

2. Literature Review

2.1 Macroeconomic Reversal Rate

In the theoretical literature, the effects of monetary policy in a low interest rate environment are mostly assessed through a standard representative agent New Keynesian (RANK) model, which includes a zero lower bound (ZLB). In our analysis, we do not consider the ZLB to be the defining threshold, as we investigate changes in the monetary transmission mechanism in a low versus normal interest rate regime and we notice modifications in the vicinity of the ZLB as well. However, we consider the theoretical literature on the ZLB to provide relevant explanations for the change in monetary transmission channels that we observe in our analysis.

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. 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

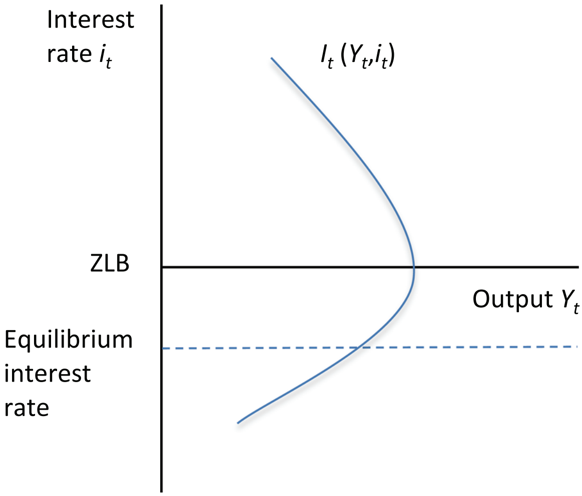
(Basu and Bundick 2017; Guerrieri and Lorenzoni 2017). The equilibrium can be restored by reducing the real policy rate via higher inflation expectations (Schmitt-Grohé and Uribe 2017; Jarociński and Maćkowiak 2018) or fiscal policy expansion (Christiano, Eichenbaum, and Rebelo 2011; Eggertsson 2011). 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 away from an equilibrium. A negative nominal interest rate functions like a macroeconomic reversal rate, which stimulates savings and discourages investment in capital goods ("investment saturation"). In Palley's model, investments and savings are driven by nominal interest rates. Agents borrow because they are liquidity constrained, while nominal debt service payments are relevant. A key role in Palley's (2019) model is played by nonreproduced 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 toward 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 can even bend backwards and become reversely elastic with respect to the interest rate, implying that investment demand I_t falls if the rate decreases.

[1]Palley's (2019) choice to put the threshold, under which resources are diverted to NRAs, at zero is somewhat arbitrary. The return on investment can become negative due to replacement costs. The marginal return on NRAs 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 NRAs, under a negative policy interest rate all liquidity is flowing to NRAs.

Figure 1. Investment Demand

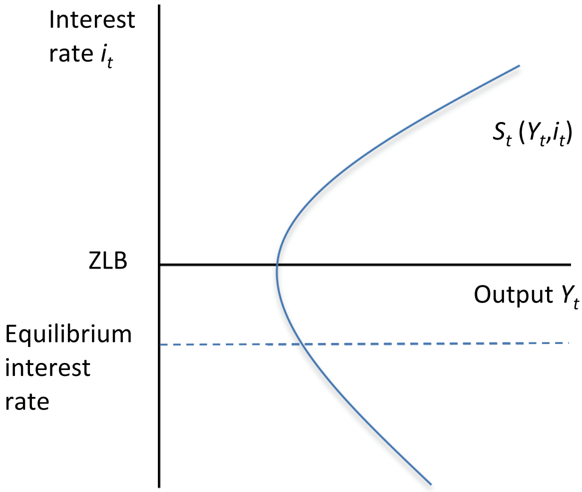


The backward-bending part of the demand curve can be associated with negative marginal returns on capital, reflecting a negative natural interest rate. The more negative the marginal returns become, the more investment demand will fall.

McKay and Wieland (2022) 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 around 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 (2022) 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 S_t. 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

Figure 2. Savings Supply



nominal returns on bank accounts or diminishing pension wealth) dominates the usual substitution effect.

2.2 Previous Empirical Evidence

An extensive literature examines the transmission of monetary policy shocks and the relationship between interest rates and spending in a linear setting. For instance, Ascari, Magnusson, and Mavroeidis (2021) use aggregate U.S. data over a long time period to estimate the consumption–interest rate relationship while controlling for returns of the 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.[2] In estimations for G7 economies over the period 1982–98, Goodhart and Hofmann

[2]Note that nonlinearity considered in Ascari, Magnusson, and Mavroeidis (2021) refers to nonlinearity due to model parameters and does not account for

(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) find a weakly significant effect of the real interest rate on consumption in a sample of 12 EA countries during 1998–2003.

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 analyze the relationship between consumption growth and interest rates and account for nonlinearities using piecewise 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 identify distinct interest rate regimes and cannot examine the dynamic reaction of consumption to interest rate changes. In addition, 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 account for a possible endogeneity between interest rates and spending by employing exogenous monetary policy shocks, constructed for the EA by Jarociński and Karadi (2020) (JK2020, henceforth). Using shocks instead of ex ante

nonlinearity due to different interest rate regimes. The latter is the specific focus of our research.

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 about inflation).

The state dependence is modeled by an STLP 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.[3] 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 for the EA aggregate:

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

where y_{t+h} is a dependent variable denoting investment, savings, consumption (all in log-levels),[4] or the output gap in period $t+h$; $h = 0, 1, 2, \ldots H$ is a projection horizon, set to 16 quarters; and 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

[3] The same approach is applied by Auerbach and Gorodnichenko (2012) and Ramey and Zubairy (2018) to analyze the effects of fiscal policy shocks on gross domestic product (GDP) growth.

[4] 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 6.4).

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 modeled as a logistic function of the interest rate as a state variable, taking the following form:

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

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.

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 percent of the sample.[6] The threshold value c is different for each economy and also for various measures of the interest rate (nominal or real, short or long term) and alternative state variables. We check the robustness of our results to various calibrations of this parameter in Section 6. A potential issue with using an interest rate as state variable is that it can be endogenous to the dependent variable y_{t+h}. This could lead to endogeneity bias in the estimates of impulse responses

[5]Estimating the models with two lags for the dependent variable instead of one does not qualitatively affect the results, although the confidence intervals become somewhat wider, resulting in less significant impulse responses.

[6]We follow Auerbach and Gorodnichenko (2012), Tenreyro and Thwaites (2016), and Ramey and Zubairy (2018), 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.

(Gonçalves et al. 2022). To address this issue, we complement the baseline analysis by using alternative state variables that are exogenous to y_{t+h} by nature.

The speed of transition (θ) between the low and the normal interest rate regimes is calibrated by assessing how quickly the probability weights move between the bounds of the interest rate levels. Following Auerbach and Gorodnichenko (2012) 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.[8] 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., $0 < F(z_t) < 1$).

For the EA panel of 10 countries, the time-series equation (1) is adapted to a panel model that takes the following form:

$$\begin{aligned} y_{i,t+h} = \tau t + F(z_{i,t}) \left(\alpha^l_{i,h} + \beta^l_h mps_t + \gamma^l_{h,p} L\left(p\right) X'_{i,t}\right) \\ + (1 - F(z_{i,t}))(\alpha^n_{i,h} + \beta^n_h mps_t + \gamma^n_{h,p} L(p) X'_{i,t}) + \varepsilon_{i,t}, \quad (3) \end{aligned}$$

[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.

[8]We follow the convention of using a maximum lag order of autocorrelation $h + 1$, where $h = 16$.

where subscript i refers to the individual countries; $\alpha^{l}_{i,h}$ are country-specific fixed effects that are interacted with the state indicator function $F(z_{i,t})$ with $z_{i,t}$ being the country-specific state variable where applicable. The time trend τt remains the same across countries, as the panel is strongly balanced.

The local projections approach has several advantages compared to a typical vector autoregression (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 easily be adapted to include nonlinearities (see Jordà 2005; Barnichon and Brownlees 2019).

4. Data

Our sample covers quarterly data for the EA aggregate and a panel of the 10 largest EA countries—Austria (AT), Belgium (BE), Germany (DE), Finland (FI), France (FR), Ireland (IR), Spain (ES), Italy (IT), Netherlands (NL), and Portugal (PT) over the period 1999:Q1–2019:Q4. These 10 countries together accounted for about 97 percent of total EA GDP on average during 1999–2019. For both the EA aggregate and the panel model, we use the same monetary policy shock, given that EA member states share a common monetary policy. We note that the panel specification has a disadvantage of imposing the same parameters for all countries, which does not capture variability in monetary policy transmission mechanism across EA countries. 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 lead to 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. The cross-country heterogeneity is further exploited in Section 5.4 where we use also a country-specific state variable.

4.1 Variable 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 the nominal short-term interest rate (three-month interbank rate). To account for possible endogeneity between the state variable and the response variables, we replace the nominal short-term interest rate with the natural interest rate (r^*), trend inflation, and the sovereign spread of EA countries as alternative state variables (see Section 5.4). In Section 6.3, the robustness section, we also use several other interest rate measures—in particular, short-term real rate, long-term rate, and shadow rate. 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), the gross household savings, total private consumption, and the output gap, as well as financial wealth. All variables (except the output gap) are seasonally adjusted volumes in EUR mln. For additional analysis, we also use real GDP (chain-linked volumes (2015) in EUR mln, seasonally and calendar adjusted) and the Harmonised Index of Consumer Prices (HICP) (2015=100). In order to investigate the bank lending channel, we use the bank lending rate and bank credit volume as alternative response variables.

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. To control for the state of the economy, we also include the real GDP (in log-levels) as a control variable.

The time series for macroeconomic, financial, and interest rate variables are obtained from the OECD statistical database, the European Central Bank's (ECB's) Statistical Data Warehouse (SDW), and Eurostat, complemented with national sources. The output gap is sourced from the Oxford Economics database. See Table A.1 in Appendix A for a description of data sources and variables. 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 shocks from JK2020, updated until October 2022.[9] The authors use a sign-restrictions identification approach and separate monetary policy shocks from contemporaneous central bank information shocks by analyzing a high-frequency comovement of interest rates and stock prices in a narrow window around monetary policy announcements. These also include announcements about unconventional monetary policy instruments used by the ECB, such as asset purchases and forward guidance. Such announcements may influence market interest rates and are thereby incorporated into the shocks. Specifically, a monetary policy shock is identified by a negative comovement 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 the intraday variation around the ECB policy announcements in EONIA (euro overnight index average) interest rate swaps and the Euro Stoxx 50, a market-capitalization-weighted stock market index including 50 blue-chip companies.[10]

In Appendix B we check how the monetary policy shock of JK2020 affects standard macroeconomic variables in the EA, i.e., real GDP, HICP, and real stock prices (all in log-levels) as dependent variables in Equation (1), with the interest rate regimes defined by the nominal short-term interest rate. Based on these outcomes, we conclude that the employed monetary policy shocks are well identified and therefore well suited for our empirical setting.

As a robustness check we employ the central bank information shock from JK2020. Their monetary policy shock is identified by assuming no correlation between the two shocks over the sample,

[9]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.

[10]The interest rate surprise in JK2020 is the first principal component of surprises in interest rate derivatives with maturities of one month, three months, six months, and one year. The surprises in interest rates and stock prices are constructed based on the Thomson Reuters Tick History data set.

but their sample differs somewhat from ours. Therefore, we examine whether the responses of our key variables differ for a central bank information shock compared with a monetary policy shock. In addition, we employ the monetary policy surprises of Altavilla et al. (2019)—in particular, the Target factor (associated with policy rate changes) and the Quantitative Easing (QE) factor (loading on longer-term yields). These surprises capture the difference in impulses coming from policy rate changes (conventional measure) and QE (unconventional measure).

5. Empirical Results

This section presents the main results for the linear and state-dependent models. The interest rate regimes in the state-dependent model are defined using the nominal 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 substantial changes in monetary policy transmission across the two regimes, as the impulse response functions are significantly different in the normal rate regime compared with the low rate regime. We find that investments, consumption, and savings respond in opposite directions to an expansionary monetary policy shock across the regimes.

In the normal rate regime, an expansionary monetary policy shock increases the investment volume in the EA. However, in the low rate regime the responses reverse, implying that further monetary easing in a low interest rate environment might not stimulate investment. This result is in line with the theoretical framework of Palley (2019), which points to the reversal of investment behavior in a low rate environment due to negative marginal returns on capital. The results for consumption are comparable to the ones for investment in terms of the signs of responses, although the magnitude of the estimated effect is smaller. Furthermore, we find that savings increase after an expansionary monetary shock in the low rate regime. This finding is consistent with Palley's (2019) model and indicates that in a low interest rate environment further monetary policy easing would raise savings, potentially due to precautionary motives or 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. 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. This 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). We expect spending to behave differently in the low rate regime. Based on the 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 behavior.

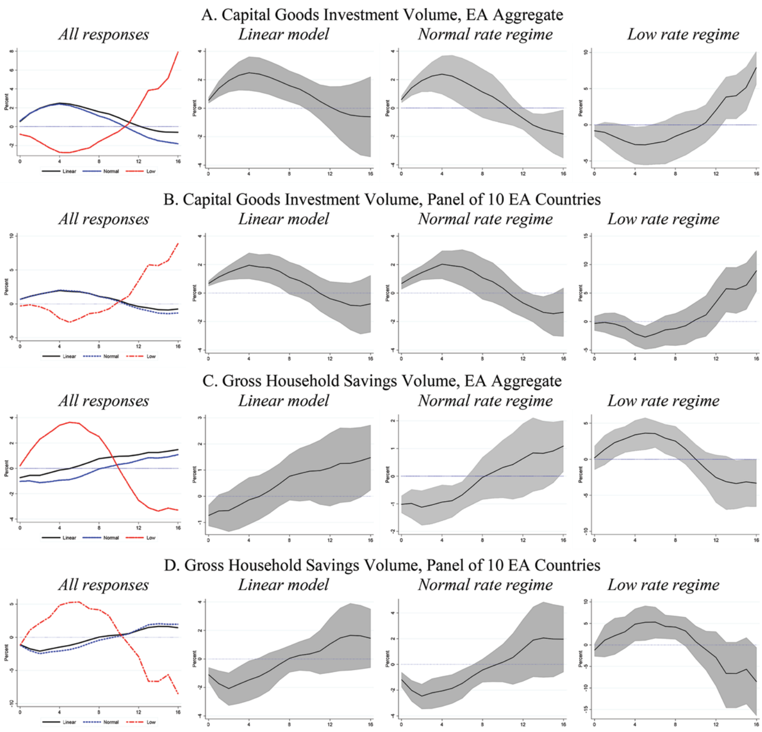
Our prior for the response of savings is that an expansionary monetary policy shock is expected to reduce savings in the normal rate regime, in line with theory. In the low rate regime, the response of savings is expected to reverse and become positive, implying that further monetary easing stimulates savings once the economy is in a low interest rate regime. We test our conjectures empirically. Figures 3 and 4 show the impulse responses for the EA aggregate and for the panel of 10 EA countries.[11] First, we report the results for investments and savings, consistent with the framework in Section 2. Next, we discuss consumption as another spending component. Lastly, we show results for the output gap as a general macroeconomic indicator.

5.2 Investments and Savings

The impulse responses of capital goods investment to an expansionary monetary policy shock are positive and significant for the EA aggregate (see Figure 3A) and the EA panel in the linear model (Figure 3B). A one standard deviation monetary easing shock implies an increase in investment in the EA by 2.5 percent at the peak, reached four quarters after the shock. The positive effect stays significant for up to 10 quarters. The response of investment in the

[11] 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.

Figure 3. Impulse Responses of y_{t+h} (investments and savings) to One St. Dev. Expansionary Monetary Policy Shock ($c = -0.1$, nominal short-term interest rate)



Note: 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 EA sample and the panel of 10 EA countries. In the first column, the solid black line shows the response in the linear, state-independent model, the blue dashed line shows the response in the normal interest rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

panel model is less strong in terms of the peak magnitude (around 2 percent), though the confidence band is narrower.

In the normal rate regime, an expansionary monetary policy shock raises private investment in the EA by 2.4 percent at the peak and the effect endures over six quarters. The investment response in the panel model is comparable, again with a narrower confidence interval. In the low rate regime, the responses are reversed for both the EA aggregate and the panel specification. In both models the investment volume declines after an expansionary monetary shock by about –3 percent at the trough and the negative effect lasts for four to six quarters, though this effect is weakly significant at 90 percent level. The impulse responses of investment in the normal and low rate regime are significantly different for the entire horizon in the EA aggregate (as indicated by a joint chi-square test in Appendix C). 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, panels C and D), both for the EA aggregate and the country panel. In the linear model and in the normal rate regime, gross household savings decline immediately after an expansionary monetary policy shock by up to –1 percent in the EA aggregate and by –2 percent in the EA country panel at the trough. This effect in the normal rate regime stays negative and significant for eight quarters.

In the low rate regime, savings strongly increase after an expansionary monetary shock. The magnitude of the savings' rise in the low rate regime (4–5 percent at the peak) is larger than the savings' drop in the normal rate regime (–1 or –2 percent at the trough). This holds both for the EA aggregate and the panel estimations. These findings are in line with our hypothesis, indicating that in a low interest rate environment further monetary policy easing would raise savings.

The first columns in Figure 3 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.[12] The results of the

[12]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.

test based on the EA aggregate sample (see Table C.1 in Appendix C) 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 nonlinearity in the estimated effect of monetary policy shocks on investment and savings.

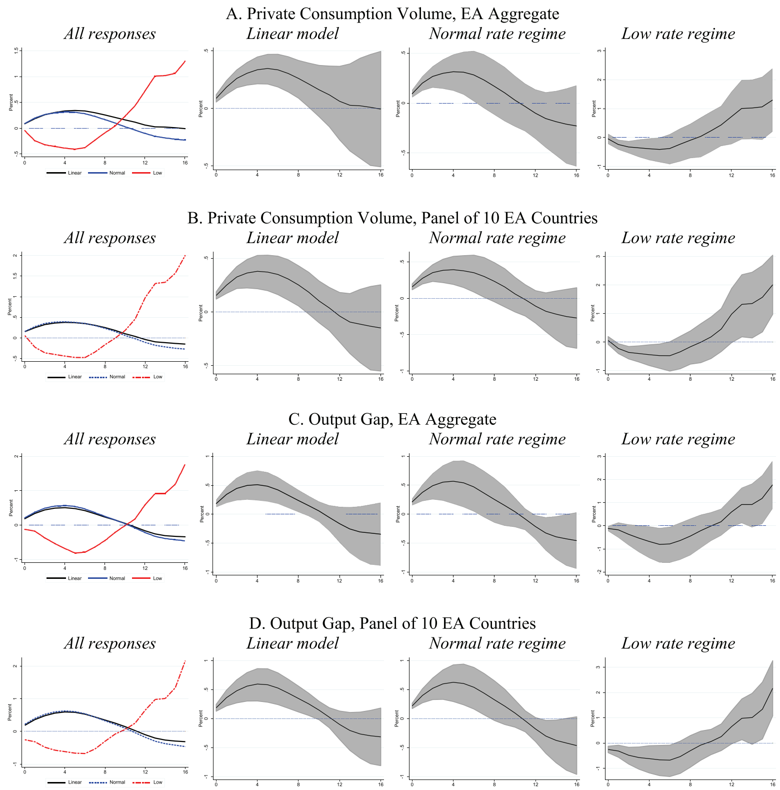
5.3 Consumption and Output Gap

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, panels A and B). Total private consumption increases significantly after an expansionary monetary policy shock in the linear model, both in the EA aggregate and in the panel sample. The responses vary between the normal and low interest rate regimes. In the normal rate regime, an expansionary monetary shock raises consumption in the EA and the panel by around 0.4 percent at the peak; this response is significant for six quarters. In the low rate regime, the negative response of consumption is a bit stronger, albeit less significant. For the EA and the panel, consumption declines by almost –0.5 percent at the trough after an expansionary monetary policy shock.

Overall, these results suggest that consumption behavior following a monetary policy shock differs across regimes: in the normal rate regime consumption increases, while in the low rate regime its response is (weakly) significant and negative. This implies that in a low interest rate environment further monetary easing might not stimulate private consumption but somewhat discourage it.

The impulse responses of the output gap point to a significant positive effect of a monetary easing shock in the linear model (see Figure 4, panels C and D). An expansionary monetary shock raises the output gap in the EA by 0.5 percent at the peak, reached four quarters after the shock; this response stays positive and significant for eight quarters. The response in the panel model is slightly stronger in terms of magnitude and endures for about 10 quarters.

Figure 4. Impulse Responses of y_{t+h} (consumption and output gap) to One St. Dev. Expansionary Monetary Policy Shock ($c = -0.1$, nominal short-term interest rate)



Note: 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 EA sample and the panel of 10 EA countries. In the first column, the solid black line shows the response in the linear, state-independent model, the blue dashed line shows the response in the normal interest rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

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 over

0.5 percent at the peak for the EA and the country panel, with the response persisting for six to eight quarters. In the low rate regime, the response of the output gap is weakly significant and negative, both in the EA and the country panel, reaching –0.8 percent at the trough.

The impulse responses of private consumption and the output gap to an expansionary monetary shock in the EA aggregate sample 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 C.1 in Appendix C). This provides evidence for the existence of nonlinearity in the impact of monetary policy shocks on consumption and the output gap.

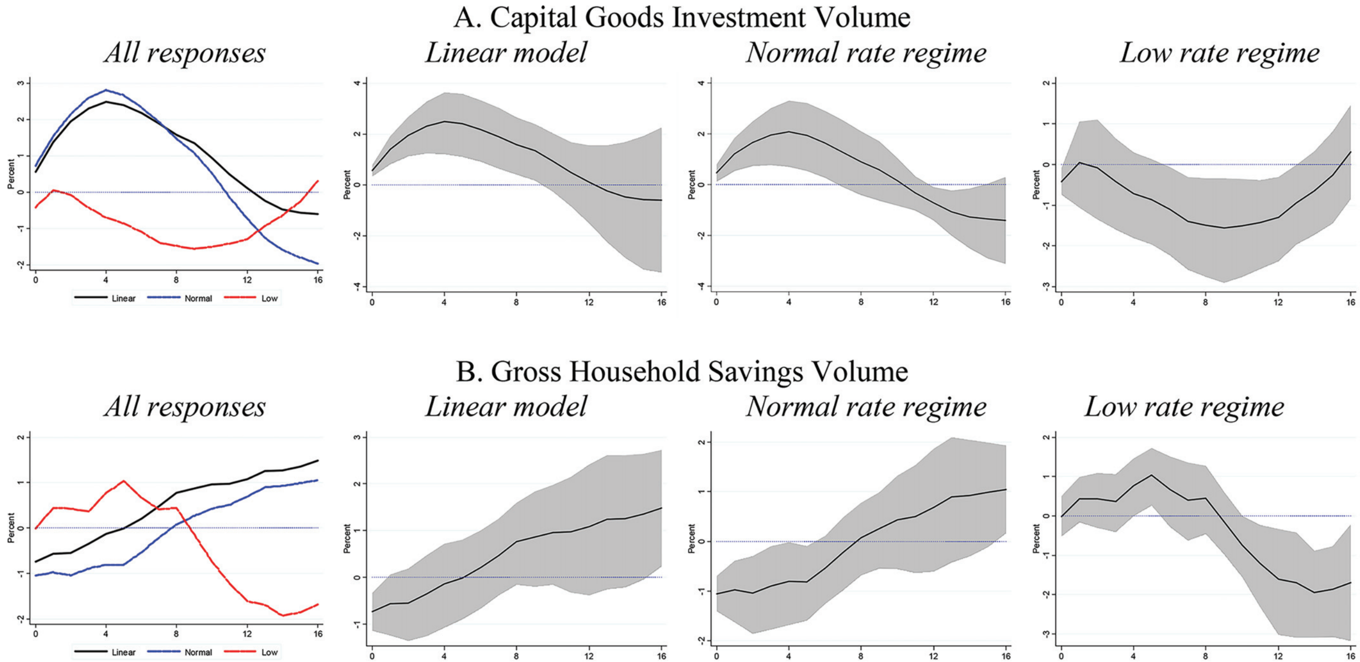
5.4 Endogeneity

A potential issue with using an interest rate as state variable is that it can be endogenous to the dependent variable y_{t+h}. This could lead to an endogeneity bias in the estimated impulse responses, as Gonçalves et al. (2022) point out. We address the endogeneity concerns in two ways. First, we estimate the STLP model using state variables that can be considered exogenous to y_{t+h}. Second, we split the sample period into pre-ZLB and ZLB subperiods.

The first approach takes trend variables that are determined outside our model as state variables, based on the argument that monetary policy (in theory) does not react to structural economic trends, although its effectiveness (policy space) is influenced by such trends. In particular, we use the natural interest rate (r^*, one-sided estimate) as defined by Holston, Laubach, and Williams (2017). r^* captures structural economic and financial trends that are determined outside of our model. Furthermore, we use trend inflation (based on the Hodrick-Prescott filter) and the sovereign spread (10-year bond yield of individual countries over the 10-year overnight index swap, or OIS, rate) as alternative state variables.

Figure 5 shows the estimated responses for investment and savings when the natural rate is used a state variable. The outcomes are largely in line with our main results reported in Figure 3. In the normal rate regime, the investment volume significantly increases, and savings drop after an expansionary monetary shock. In the low

Figure 5. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, State Variable—Natural Interest Rate, $c = 0.2$



Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

rate regime the responses are opposite in terms of sign but borderline significant. Nevertheless, the results indicate that the analyzed macroeconomic variables behave differently in the two regimes. The responses for private consumption and the output gap are very similar to Figure 4, and more strongly significant in the low rate regime (available on request).

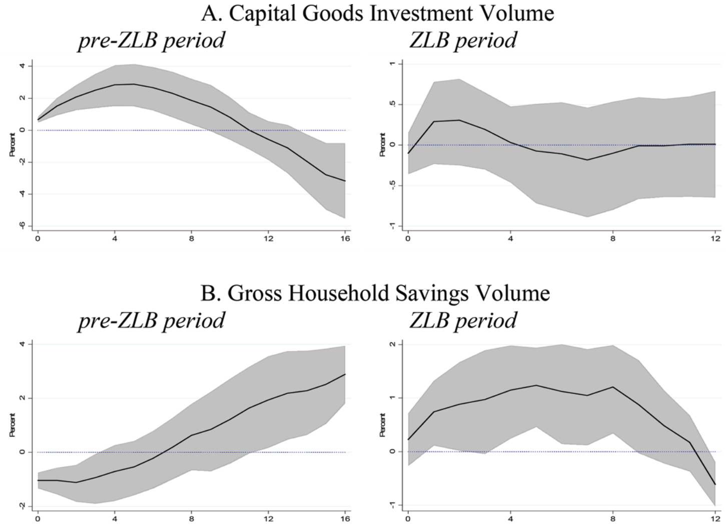
The outcomes based on trend inflation as alternative state variable are reported in Figure D.1 (Appendix D). The outcomes display similar responses as our main results, i.e., investments decrease and savings increase in the low rate regime (and vice versa in the normal rate regime).

To further exploit the cross-country heterogeneity, also in the determination of the regimes, we take the sovereign spread as state variable in the panel model. It implies that both the state variable and its threshold are country specific. The use of the sovereign spread takes into account the heterogenous impact of financial shocks in the EA, which might lead to a flight to safety of capital flows from crisis-prone countries toward countries that are perceived safer by investors. The outcomes in Figure D.2 (Appendix D) show that the responses of investments and savings are comparable to the outcomes of the panel model with the short-term nominal rate as a state variable (Figure 3B). In the nonlinear model, the confidence bands of the responses are wider, while the responses of savings are not statistically significant. This could be due to the much shorter sample size in this specification.

While these alternative state variables could partly address the endogeneity issue, we do not use them as baseline state variables since they also have drawbacks. The natural rate and trend inflation are estimates and therefore depend on modeling assumptions and add uncertainty when they are included in another model. The sovereign spread is only available from 2005 onward (due to data availability for the 10-year OIS rate), which shortens our sample, making the inference less reliable.

The second approach to make the identification of interest rate regimes independent from any (potentially endogenous) state variable splits the sample period into two subperiods, taking as a breakpoint the ECB Governing Council's decision to lower the deposit facility rate to 0 percent in July 2012. Hence, we distinguish the pre-ZLB period (until 2012:Q3) and the ZLB period (from 2012:Q3

Figure 6. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA, Subsamples: pre-ZLB Period (1999:Q1–2012:Q2) and ZLB Period (2012:Q3–2019:Q4)



Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA aggregate sample, with a 90 percent confidence interval around the responses (shaded area). For the ZLB period, the responses are calculated in the horizon $h = 12$ to account for the small number of observations in this subsample (N = 30).

onward). We estimate the impulse responses of investments and savings based on linear LP models for each subperiod (see Figure 6). The results for both dependent variables in the pre-ZLB period are similar to STLP results corresponding to the normal rate regime. While in the ZLB period the response of investments is insignificant, the response of savings is in line with our results in the low rate regime. This outcome is not surprising given that the probability of being in a low rate regime (F function) is also quite binary and increases around the period when the policy rate became zero (2012) or negative (2014). The caveat of the subsamples exercise is the relatively short time period of the low rate regime in our sample (the ZLB period includes 30 observations).

5.5 Additional Response Variables

As an extension, we consider additional response variables in our STLP model. First, we use households' financial wealth (in log-level) as a dependent variable to capture the wealth effect. The results based on the baseline specification (with nominal short-term rate as state variable and EA aggregate sample) are reported in Figure E.1 in Appendix E. In the linear model and the normal rate regime, financial wealth increases after an expansionary monetary policy shock, suggesting that benefits from higher asset prices might outweigh the losses on interest-bearing savings due to lower deposit rates. In the low rate regime the effect reverses—households' financial wealth decreases after an expansionary shock, which could be explained by lower returns on lifetime (pension) savings due to lower long-term rates not being fully offset by the rise in asset prices. This wealth effect could be related to the strong positive response of savings volume in the low rate regime, as households save more to compensate for wealth losses in a low interest rate environment.

Next, we add bank lending rates (average lending rate on loans to firms and households) and volumes (total bank credit to private nonfinancial sector, in log-level) as response variables in the STLP model. As hypothesized in Section 1, low interest rates can have adverse effects on investments in capital goods through the bank lending channel. That is, in a low rate environment a lower policy rate can lead to higher instead of lower lending rates and thereby reduce lending. The results (Figure E.1) partly support this hypothesis. On the one hand, responses of lending rates in different regimes are insignificant. This may indicate that the bank lending channel is not sufficiently well captured by an aggregate lending rate, and one needs to distinguish interest rates separately for household and corporate lending, maturity, or type of loans on a micro level for a better grasp of the underlying mechanism. On the other hand, responses of credit volumes are in line with our conjecture: in a low rate regime an expansionary monetary shock leads to a decline (and not an increase, like in a normal rate regime) in bank credit. Thus, in a low rate environment, banks might be less inclined to lend, while elevated risk-taking and search for yield make alternative investments more appealing than lending. As a result of lower credit supply, investment in capital goods may drop, as shown in Figure 3.

6. Sensitivity Analysis

6.1 Different Shocks

We explore the robustness of our results to the employed shocks. First, we check whether the estimated effects are sensitive to the use of a central bank information shock. Second, we employ the monetary policy shocks by Altavilla et al. (2019) instead of the JK2020 shocks, to take into account possible differences in the effects of policy rate and QE surprises. Finally, 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).

First, we employ the central bank information shock from JK2020 instead of the JK2020 monetary policy shock used in the baseline. Based on the baseline sign restrictions used for identification of these shocks and a low negative correlation between the two (correlation coefficient of –0.04 in our sample), we expect the two shocks to behave differently and induce a different reaction of the macroeconomic variables. Figure F.1 in Appendix F confirms this conjecture: the impulse responses of investment to an expansionary central bank information shock have the opposite sign compared with the corresponding responses to an expansionary monetary policy shock, in the linear model and in the normal rate regime. In the low rate regime the responses are not significantly different from zero. For savings, the responses in the linear model are consistent with the baseline results using the monetary policy shock, but insignificant in normal and low rate regimes. This finding is in line with JK2020, who report that the responses of 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.

Next, we address the potential ZLB concern that might arise from our empirical setup. Specifically, in our sample the threshold for the nominal short-term interest rate used as a baseline state variable to split the interest rate regimes coincides with a rate of –0.1 percent, which might give the impression that we identify a ZLB regime instead of a low rate regime. In order to account for this, we separate the effect of the ZLB from the effect of low interest rates by distinguishing monetary policy shocks that are associated with changes in policy rate (reflecting low rates) from shocks associated with QE measures (reflecting the ZLB). For this purpose, we employ the monetary policy surprises constructed by Altavilla et al. (2019). In particular, we use the time series based on the Target factor (which is associated with the policy rate shocks, reflecting conventional monetary policy or low short-term nominal rates) and the time series based on the QE factor (which loads only on longer-term yields, reflecting unconventional monetary policy at the ZLB). Once the ZLB was binding, there were fewer Target factor shocks and their effects were confined to the short end of the yield curve, with a rapid decay (see Altavilla et al. 2019). However, the Target factor is not minimal by definition at the ZLB, since it captures surprise revisions of market participants' expectations, based on changes in the short end of the yield curve during the ECB's monetary policy press releases. Such surprise revisions also took place in the ZLB episode, which resulted in a set of Target shocks.

The results in Figure F.2 show that the responses of investment and savings to a one standard deviation expansionary shock in the Target factor (reflecting lower policy rates) are very similar to the ones for the JK2020 expansionary monetary policy shock, both in normal and in low rate regimes. Meanwhile, the responses to the expansionary QE factor shock (reflecting lower long-term yields) differ from our baseline results. In particular in the low rate regime, both investment and savings do not respond significantly to the QE shock (Figure F.3). We can thus conclude that our main results from a conventional monetary policy shock do not coincide with an unconventional monetary policy shock, and as such, our low rate regime identification is different from ZLB-regime considerations.

To test whether the responses of macroeconomic variables to the baseline monetary policy shock are asymmetric, we separate the monetary policy shock series into a positive and a negative series. The negative (positive) series takes the values of a shock when it is negative (positive) and 0 otherwise, such that each series is simultaneously interacted with the state probabilities (we do not observe cases when the monetary policy shock is equal to 0). This yields four shock coefficients to be estimated in the STLP. For comparability, the impulse responses to both positive and negative shocks are always displayed as responses to a one standard deviation decrease in the shock. Hence, if responses comove across positive and negative shocks, no asymmetry is present. Responses moving in opposite directions would indicate asymmetry. All responses are depicted in Figure F.4 in Appendix F.

For investment and savings, the responses to a one standard deviation decrease in the positive shock series, displayed in the first row in Figure F.4, broadly align with the baseline estimation. For the negative shocks, we observe some difference in the low rate regime toward the end of the projection horizon for investment and mostly insignificant results for savings. These differences in investment responses may be due to the signaling effect on the state of the economy that becomes more relevant in the low rate regime. For positive shocks, the responses move in opposite directions across normal and low rate regimes as expected. However, one needs to consider the results with caution, especially in the low rate regime for negative shocks. There are overall fewer negative shocks (41 percent) while the low rate period is overall shorter such that estimated coefficients of the exercise may be biased by the smaller "subsample."

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.

6.2 Parameters of the Smooth Transition Function

We examine the robustness of findings to modifications of calibrated parameters in the smooth transition function $F(z_t)$, i.e., 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 EA aggregate with investment or savings as dependent variables (results for other variables are available on request). Figure G.1 in Appendix G shows the probability of being in the low or normal interest rate regime (function $F(z_t)$) for speed of transition $\theta = 7$

and the threshold value $c = -0.1\%$ for the nominal short-term rate (panel A) in the EA, used in our baseline estimations in Section 5.

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 35 percent and 50 percent of the observations in the sample. This corresponds to threshold values c of the nominal short-term rate equal to 0.66 percent and 1.5 percent, respectively. Our highest calibrated threshold of 1.5 percent is close to the one used by Claessens, Coleman, and Donnelly (2018), who classify a country as being in a "low" rate environment when its three-month nominal interest rate is below or equal to 1.25 percent. In our EA aggregate sample over the period 1999:Q1–2019:Q4 this occurs in around 47 percent of observations. Thus, using the threshold value of 1.5 percent with half of the observations for the short-term rate in our sample below 1.5 percent, 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 –0.1 percent for the nominal short-term interest rate (see Table G.1 in Appendix G). 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.[13] 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. Nevertheless, these modifications do not alter our conclusions.

[13]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.

Another indication for sensitivity of the period of the low rate regime is the level of r^*. The average r^* for the EA in the pre-ZLB period (1.7 percent) was not much lower than in the preceding two decades (1980–98), when the average r^* was 2.2 percent. These rates are markedly higher than the average r^* in the ZLB period (i.e., 0.2 percent). Thus, it seems likely that the normal rate regime in our sample period is comparable to the normal rate regime in the preceeding decades. Hence, it is not obvious that if the model was estimated on an earlier sample, a relatively low rate subperiod (though with a higher interest rate compared with our low rate regime) would result in similar results as we find for the low rate regime in our sample.

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 –0.1 percent (see Table G.2 in Appendix G). 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 transition from the normal to the low rate regime is slower (i.e., $\theta = 3$). Overall, modifying the speed of transition does not affect our main findings.[14]

[14] 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 realizations 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 percent (i.e., $c = -0.1$ for nominal short-term rate as chosen in our baseline) and $\theta = 2$. 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.

6.3 State Variables in a Smooth Transition Function

To test the sensitivity of the results to the choice of an interest rate measure, we use several alternative interest rates as a state variable z_t in the smooth transition function, namely the short-term real rate (nominal rate deflated by HICP inflation), the long-term interest rate (10-year government bond yield), and the shadow rate from Krippner (2015).[15] The latter 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.

The variation in the short-term nominal 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 nominal rate is constrained by the effective lower bound, while the long-term rate and shadow rate are affected by the 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 and the shadow rate as state variables in the sensitivity analysis. The threshold value c for the interest rates is calibrated so that the low rate regime occurs in 20 percent of the sample, similar to calibration used for the short-term nominal rate. For the EA this threshold is equal to –1.35 percent for the short-term real rate, 2.5 percent for the long-term rate, and –1.6 percent for the shadow rate. The speed of transition θ is set at 7 as in baseline specification.

Figure G.1 in Appendix G shows the probability of being in the low or the normal rate regime for these alternative state variables, estimated for the EA aggregate. The timing of the low rate regime derived from these interest rates coincides generally 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 rate takes nonzero values after 2015:Q1, while this probability for the short-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 rates over time compared with the observed dynamics for short-term nominal rate. The timing of the low rate

[15] The shadow rate series of Krippner for the EA span the full sample period (1999:Q1–2019:Q4).

regime based on the shadow rate (after 2012:Q1) is quite similar to the timing for the short-term nominal rate. Note that the low interest rate regime based on short-term nominal rate and shadow rate coincides with the EA sovereign debt crisis. The latter was characterized 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 partly reflect the impact of these factors. To account for it, we include the long-term interest rate as alternative state variable. This results in a different timing of the low rate regime than for the short-term nominal rate, by dating it after 2015:Q1. The difference in timing implicitly tests for sensitivity of results to the EA sovereign debt crisis (which evolved between 2010 and 2014), since the timing of the low rate regime after 2015:Q1 for long-term rates does not coincide with the crisis. The regime probability based on the real short-term rate also starts to increase in tandem with the short-term nominal rate, but it drops to very low levels during 2014–16. In that period, inflation fell to low levels, pushing up the real short-term rate and thereby the probability of the low regime dropped.

The impulse responses of investment and savings with alternative state variables are shown in Figures G.2–G.4 (Appendix G). The responses of investments volume to an expansionary monetary policy shock, based on the long-term and shadow rates as state variables, are similar to the baseline results in the normal rate regime but insignificant in the low rate regime. The outcomes for savings using alternative interest rates are significant and 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 the estimated impulse responses are not driven by the EA sovereign debt crisis.

6.4 Other Sensitivity Tests

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 G.5) are qualitatively similar to the ones for the EA aggregate baseline model in log-levels. Specifically, an expansionary monetary policy shock increases investment growth in the EA in the normal rate regime by up to 2.5 percentage points (pp), while it reduces the investment growth in the low rate regime by –3 pp at the trough, for about two years. The responses of savings growth exhibit the opposite dynamics: savings growth drops in the normal rate regime by about –1 pp but increases by 4 pp 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.

We also include other control variables, next to the lagged dependent variable, to check the robustness of our findings. Specifically, we add financial wealth of households, the real house and stock prices (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. Furthermore, we add the log-level of real GDP as a control variable, while either including or excluding the time trend. The level of GDP controls for the state of the economy.

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 H.6–H.8). Adding the house price as a 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 or the GDP level affect the baseline results (see Figures H.9–H.11); this holds for all dependent variables and state variables 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) or the state of the economy but driven mainly by the interest rate regime.

6.5 GDP Growth as State Variable

Our findings suggest that there is a reversal in the behavior 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 percent of the state variable as a threshold below which the business cycle is considered to be in recession. Consequently, we distinguish two regimes: expansion and recession. Figure H.1 in Appendix H depicts the resulting probabilities where close to 1 (0) implies a high probability of being in recession (expansion).

Figure H.2 shows responses of investments, savings, consumption, and the output gap to a one standard deviation expansionary monetary policy shock in the EA in the linear model (second column), in expansion (third column), and in recession (fourth column). We observe very different patterns in responses under economic expansion and recession regimes compared with the results for interest rate regimes. Specifically, the impulse responses of all four macroeconomic variables in a recession have the opposite sign compared with 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 EA, 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 rate regime do not coincide with economic recession. That is, macroeconomic variables experience a reversal in their behavior in a low interest rate environment, which does not necessarily occur in a weak state of the economy. In addition, Figures H.3

and H.4 depict the low interest rate regime probabilities together with our main response variables (in levels or growth rates). They show that developments in the macroeconomic variables do not coincide with shifting to the low rate regime, suggesting that macroeconomic developments do not drive the probability of this shift.

7. Conclusion

This paper examines potential nonlinearities in the reaction of investment, spending, and savings to monetary policy shocks. We employ the STLP model to estimate the impulse responses of different aggregate demand components to an expansionary monetary policy shock in the EA aggregate sample and in a panel of the 10 largest EA countries during 1999–2019 under two distinct regimes: normal and low interest rate. Our results indicate that the monetary policy transmission varies across the two regimes, as some macroeconomic aggregates respond in an opposite way to monetary policy shocks.

In the normal interest rate regime, we detect a significant increase in private consumption, investment spending, and the output gap following an expansionary monetary policy shock. In contrast, the impulse responses of these variables reverse signs in the low rate regime, providing evidence for the existence of a macroeconomic reversal rate. While the 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 tends to raise savings. We also find that expansionary monetary policy does not enhance investment and lending in a low rate regime.

Our findings indicate that expansionary monetary policy may become less effective in a 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. The existence of such nonlinearities implies that the effectiveness of monetary policy may be limited in certain macroeconomic conditions. The level of the interest rate is a potential determinant of the interest rate sensitivity of aggregate demand, since in a low interest rate environment it is likely that the behavior of economic agents and their expectations change.

Appendix A

Table A.1. Data Description and Sources, All Variables

Variable	Definition	Data Source
Private Consumption	Final consumption expenditure of households; chain-linked volumes (2015), EUR mln, seasonally and calendar adjusted	Eurostat, Final consumption aggregates
Investment in Capital Goods	GFCF in machinery and equipment and weapons systems (gross); chain-linked volumes (2015), EUR mln, seasonally and calendar adjusted	Eurostat, Gross fixed capital formation with AN_F6 asset breakdowns
Gross Household Savings	Total assets minus debt (in nominal terms, EUR mln)	ECB, Statistical Data Warehouse
Output Gap	(Actual GDP – potential GDP) / potential GDP	Oxford Economics
GDP Level	GDP chain-linked volumes (2015) seasonally and calendar adjusted, EUR mln	Eurostat, OECD (for Spain)
Household Financial Assets	Include currency, deposits, debt securities, shares, life insurance, pension schemes, minus debt (EUR mln)	ECB, Statistical Data Warehouse
Service Ratio	Value-added service sector/GDP, s.a., current prices	Eurostat (NAMQ_10_A10)
Credit Volume	Outstanding bank loans to households and nonfinancial corporations, EUR mln	ECB, Statistical Data Warehouse
HICP Index	Index, 2015=100, n.s.a.	Eurostat
Short-Term Interest Rate	Three-month interbank rate	OECD Main Economic Indicators

(continued)

Table A.1. (Continued)

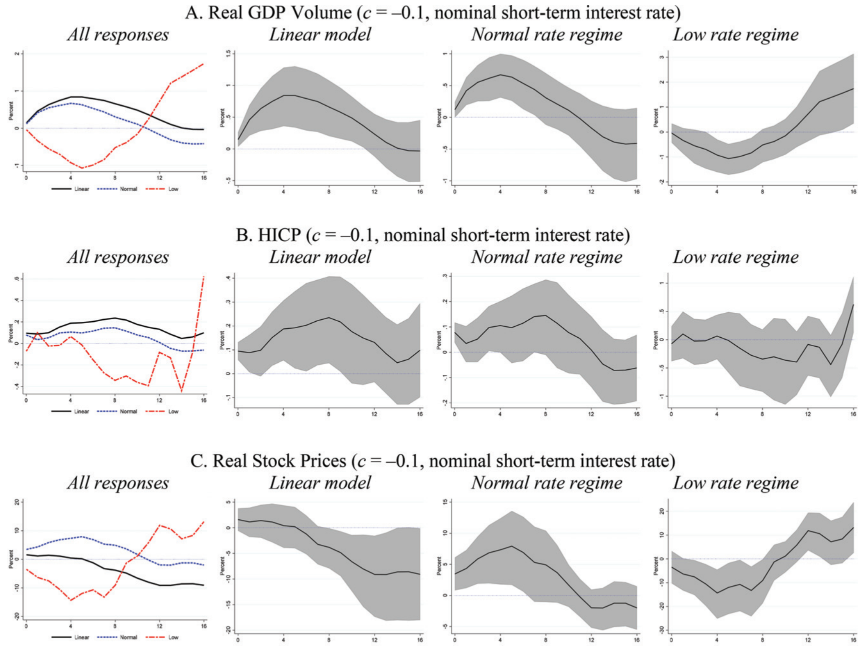
Variable	Definition	Data Source
Long-Term Interest Rate	10-year government bond yields	Refinitiv
Shadow Rate	Quarterly average, in percent	Measures of the stance of U.S. and international monetary policy—Reserve Bank of New Zealand
Lending Rate	Average of bank lending rates to household (consumption and mortgages) and new loans to nonfinancial corporations	ECB, Statistical Data Warehouse
Stock Price	National stock price index	Refinitiv
Real House Price	Index, ratio of nominal house price (s.a.) to consumers expenditure deflator (s.a.)	OECD Analytical house price database
Trend Inflation	Trend of year-on-year change of HICP index for EA (HP filter, $\lambda = 1{,}600$)	ECB, Statistical Data Warehouse
Natural Rate of Interest (r^*)	Estimated real short-term interest rate in equilibrium, based on Holston, Laubach, and Williams (2017) model. Final point: 2020:Q1	Holston, Laubach, and Williams (2017), Measuring the natural rate of interest—Federal Reserve Bank of New York
Sovereign Bond Spread (by Country)	10-year government bond yield of each country in sample minus 10-year OIS rate, quarterly average in percent	Refinitiv
Monetary Policy Shocks (1)	Monetary policy and central bank information shocks, quarterly values constructed by summing monthly values over three months of quarter	Jarociński and Karadi (2020)
Monetary Policy Shocks (2)	Shock series constructed for different monetary policy instruments, quarterly values constructed by summing monthly values over three months of quarter	Altavilla et al. (2019)

Appendix B. Impact of Monetary Policy Shocks on Standard Macroeconomic Variables

We check how the monetary policy shocks of JK2020 affect standard macroeconomic variables. For this purpose, we estimate the linear and state-dependent LP models for the EA with real GDP, HICP, and real stock prices (all in log-levels) as dependent variables in Equation (1). The interest rate regimes are defined by the nominal short-term interest rate.

We find that a one standard deviation expansionary monetary policy shock increases real GDP by 0.5–0.7 percent at the peak in the linear model and in the normal rate regime (see Figure B.1). This effect endures for two years. In the low rate regime, we observe an opposite dynamic: GDP drops by –1 percent at the trough, and the effect is significant and negative for eight quarters. The results for HICP are qualitatively similar—an expansionary shock implies a peak rise in HICP by 0.2 percent in the linear model and by 0.1 percent in the normal rate regime. The responses in the low rate regime are insignificant. Real stock prices increase after an expansionary monetary shock by 4 percent in the normal rate regime. This effect remains positive and significant for one year. In the low rate regime, the response reverses: a monetary easing shock leads to a drop in stock prices by –15 percent at the trough. 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 well suited for our empirical setting.

Figure B.1. Impulse Responses of y_{t+h} to One St. Dev. Expansionary Monetary Policy Shock, EA



Note: The figure plots smoothed impulse responses of real GDP volume, HICP, and real stock price (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal interest rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Appendix C

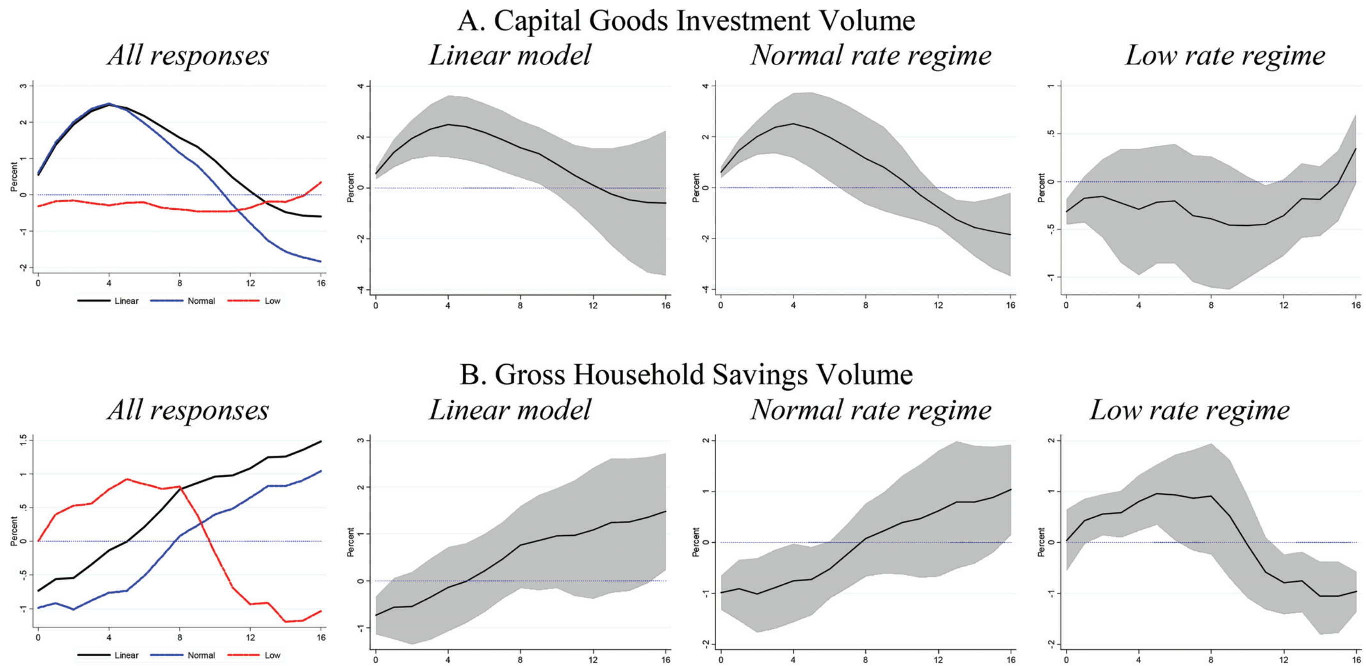
Table C.1. Joint Chi-Squared Test for Significance of Differences between the Estimated Impulse Responses, EA Aggregate, Baseline Model

	Chi(2)-Statistic	P-value
Capital Goods Investment Volume	51.46	0.000
Gross Household Savings Volume	29.75	0.028
Private Consumption Volume	37.88	0.003
Output Gap	54.40	0.000

Note: 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 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 percent and 5 percent significance level, respectively.

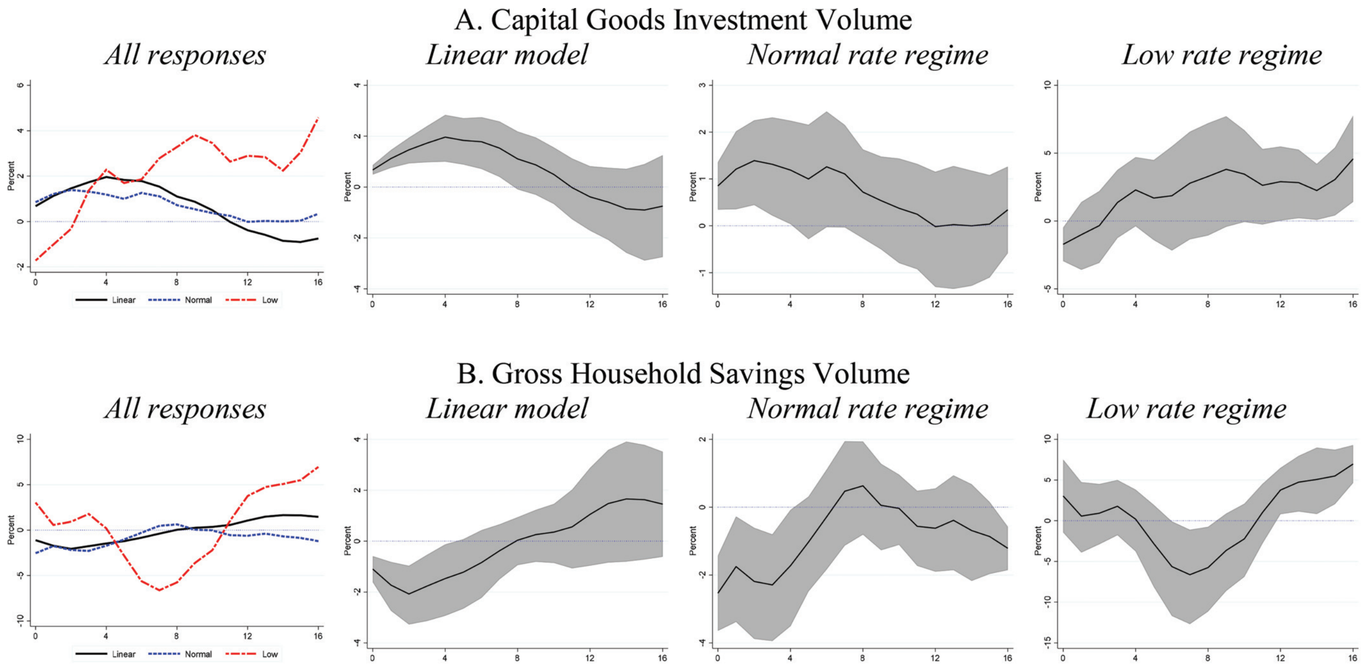
Appendix D

Figure D.1. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: State Variable—Trend Inflation, $c = 1.2$



Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

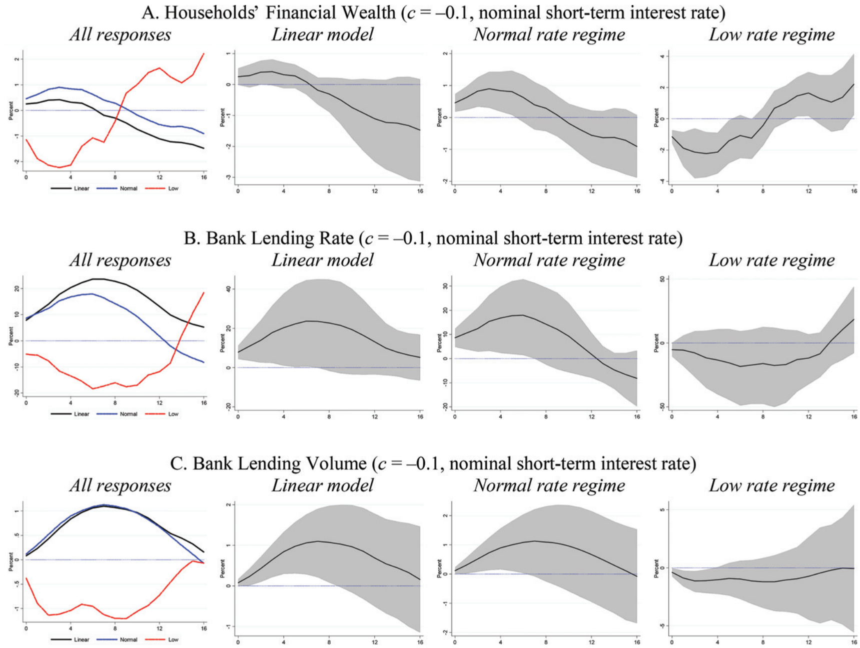
Figure D.2. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, Panel of 10 EA Countries, State Variable—Sovereign Spread, c is Country Specific



Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Appendix E

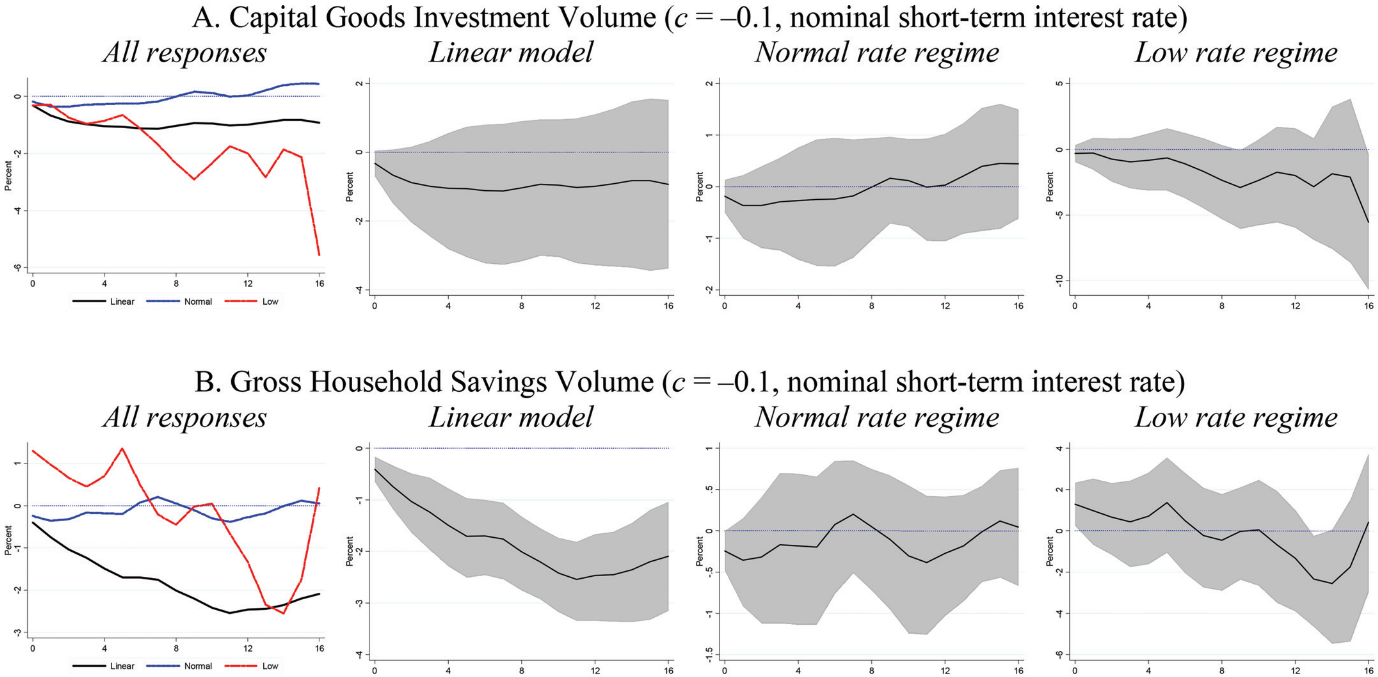
Figure E.1. Impulse Responses of Financial Wealth, Bank Lending Rate, and Bank Lending Volume to an Expansionary Monetary Policy Shock, EA Aggregate



Note: The figure plots smoothed impulse responses of households' financial wealth (log-level), bank lending rate, and bank lending volume (log-level) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around responses (shaded area).

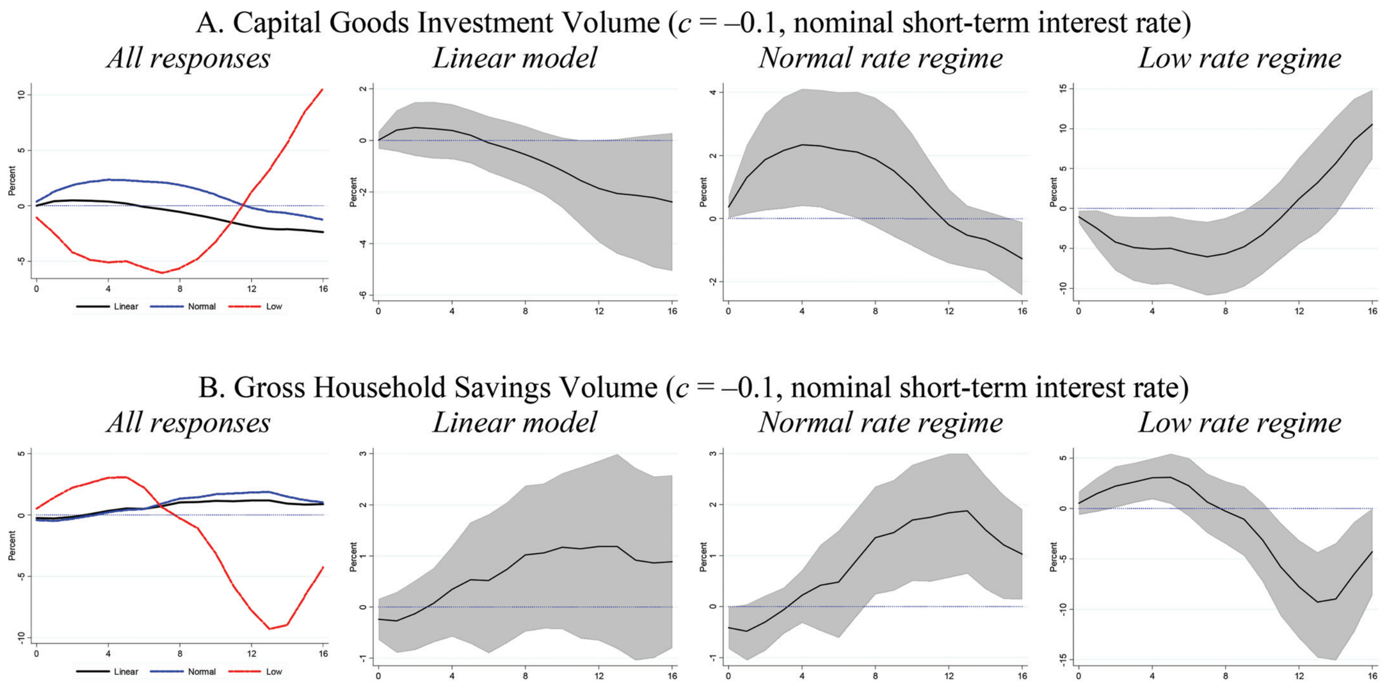
Appendix F

Figure F.1. Impulse Responses of Investments and Savings to an Expansionary Shock, EA Aggregate, Robustness Check: Central Bank Information Shock from JK2020



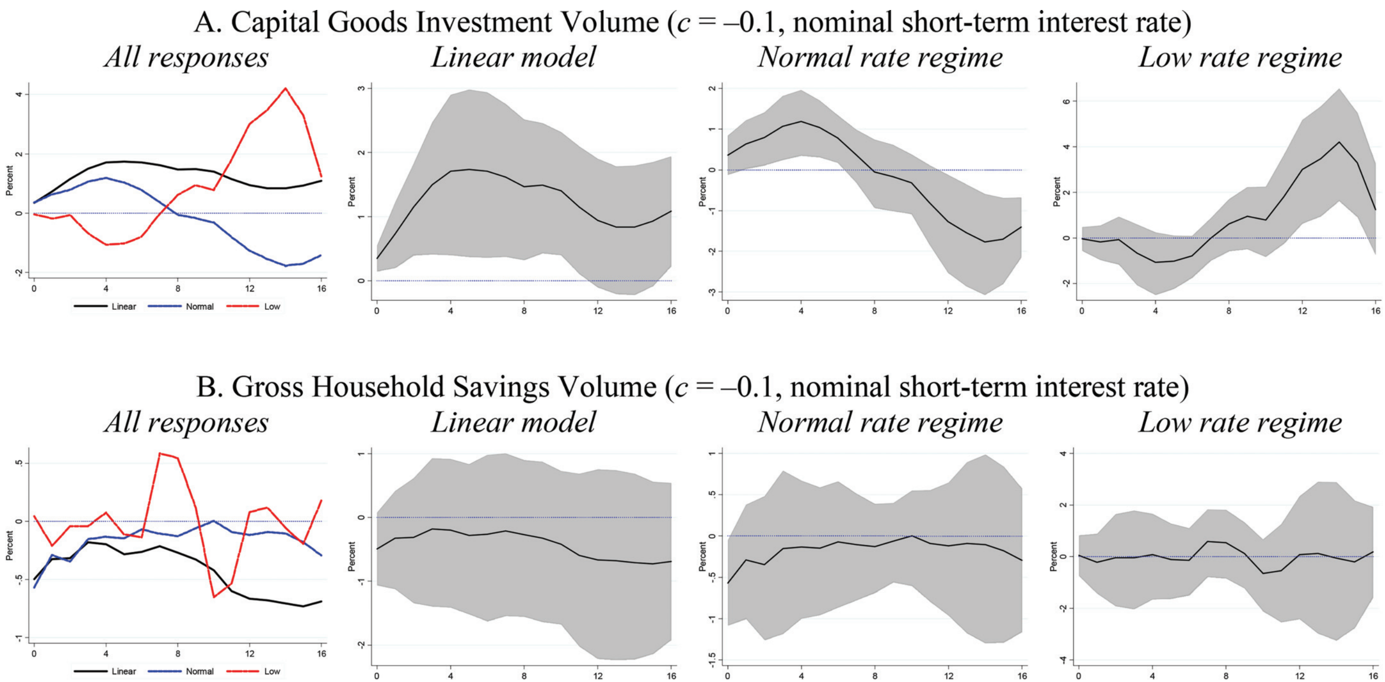
Note: The figure plots smoothed impulse responses of capital goods investment and gross household savings (all in log-levels) to a one st. dev. expansionary central bank information shock (baseline sign-restrictions identification) in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around responses (shaded area).

Figure F.2. Impulse Responses of Investments and Savings to an Expansionary Shock, EA Aggregate, Robustness Check: Target Factor Shock from Altavilla et al. (2019)



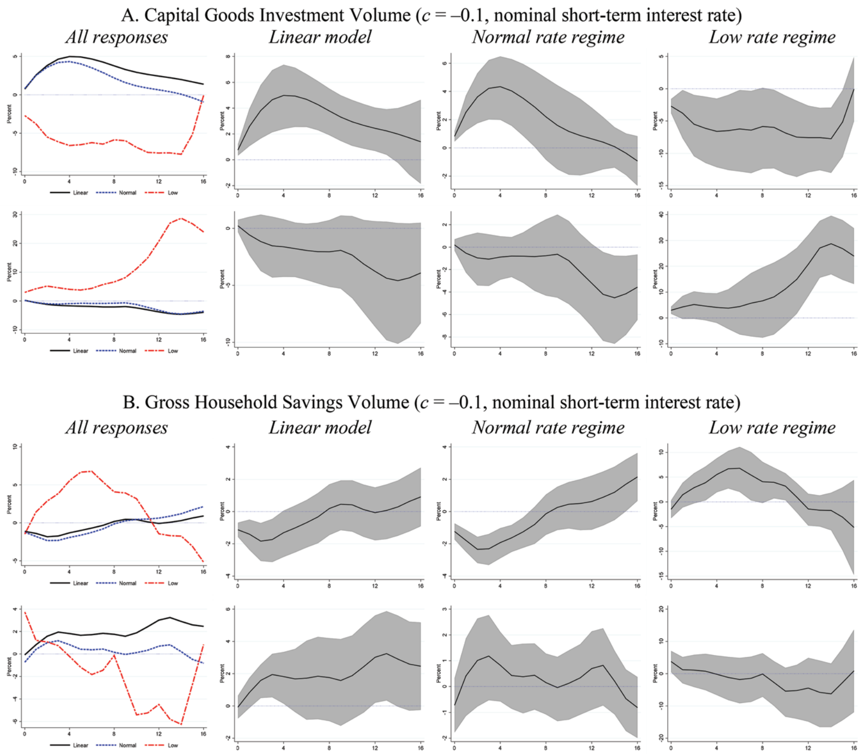
Note: The figure plots smoothed impulse responses of capital goods investment and gross household savings (all in log-levels) to a one st. dev. expansionary Target factor shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure F.3. Impulse Responses of Investments and Savings to an Expansionary Shock, EA Aggregate, Robustness Check: QE Factor Shock from Altavilla et al. (2019)



Note: The figure plots smoothed impulse responses of capital goods investment and gross household savings (all in log-levels) to a one st. dev. expansionary QE factor shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

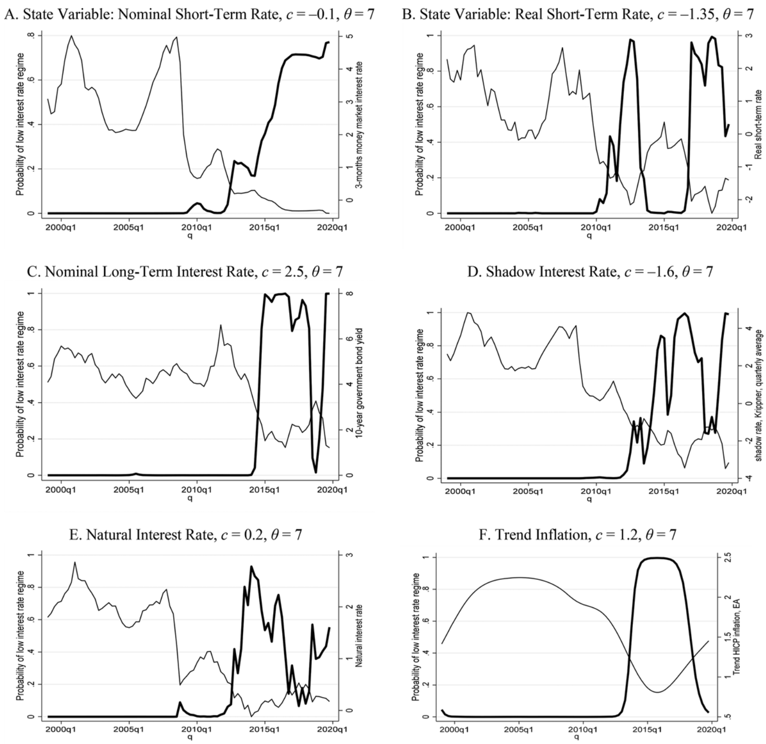
Figure F.4. Impulse Responses of Investments and Savings to an Expansionary Shock, EA, Robustness Check: Positive (rows 1 and 3) and Negative Shocks (rows 2 and 4)



Note: The figure plots smoothed impulse responses of capital goods investment and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area). Shocks are both displayed as expansionary.

Appendix G

Figure G.1. 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 $F(z_t)$, EA Aggregate



Note: 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 percent.

Table G.1. 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, EA Aggregate

EA	Baseline, $c = -0.1\%$		$c = 0.66\%$		$c - 1.5\%$	
At Horizon $h =$	**Normal**	**Low 20% Sample**	**Normal**	**Low 35% Sample**	**Normal**	**Low 50% Sample**
			Capital Goods Investment Volume			
0	0.617	−0.839	0.627	−0.166	0.627	−0.200
	(0.146)	(0.463)	(0.152)	(0.115)	(0.087)	(0.282)
4	2.409	−2.750	2.458	0.408	2.975	0.707
	(0.798)	(1.468)	(0.833)	(0.602)	(0.695)	(0.573)
8	1.134	−1.578	1.112	0.570	1.680	0.358
	(1.011)	(1.815)	(1.010)	(1.029)	(0.732)	(0.460)
12	−0.698	2.011	−0.820	−0.06	−0.419	−0.436
	(0.368)	(1.603)	(−0.372)	(0.794)	(0.611)	(0.559)
16	−1.818	7.847	−1.906	0.3819	−1.281	−1.145
	(1.067)	(1.432)	(1.189)	(0.772)	(1.127)	(0.792)
			Gross Household Savings Volume			
0	−1.027	0.226	−1.192	0.157	−1.145	−0.023
	(0.187)	(1.001)	(0.160)	(0.358)	(0.159)	(0.163)
4	−0.944	3.436	−1.137	1.407	−0.634	0.690
	(0.389)	(1.047)	(0.258)	(0.779)	(0.236)	(0.358)
8	−0.045	2.546	0.107	0.828	0.607	0.454
	(0.495)	(1.620)	(0.369)	(0.735)	(0.624)	(0.282)
12	0.640	−2.542	0.649	−0.883	1.213	−0.495
	(0.793)	(1.698)	(0.665)	(0.630)	(0.525)	(0.401)
16	1.098	−3.351	1.140	−1.144	1.384	−0.659
	(0.563)	(1.985)	(0.489)	(0.539)	(0.302)	(0.289)

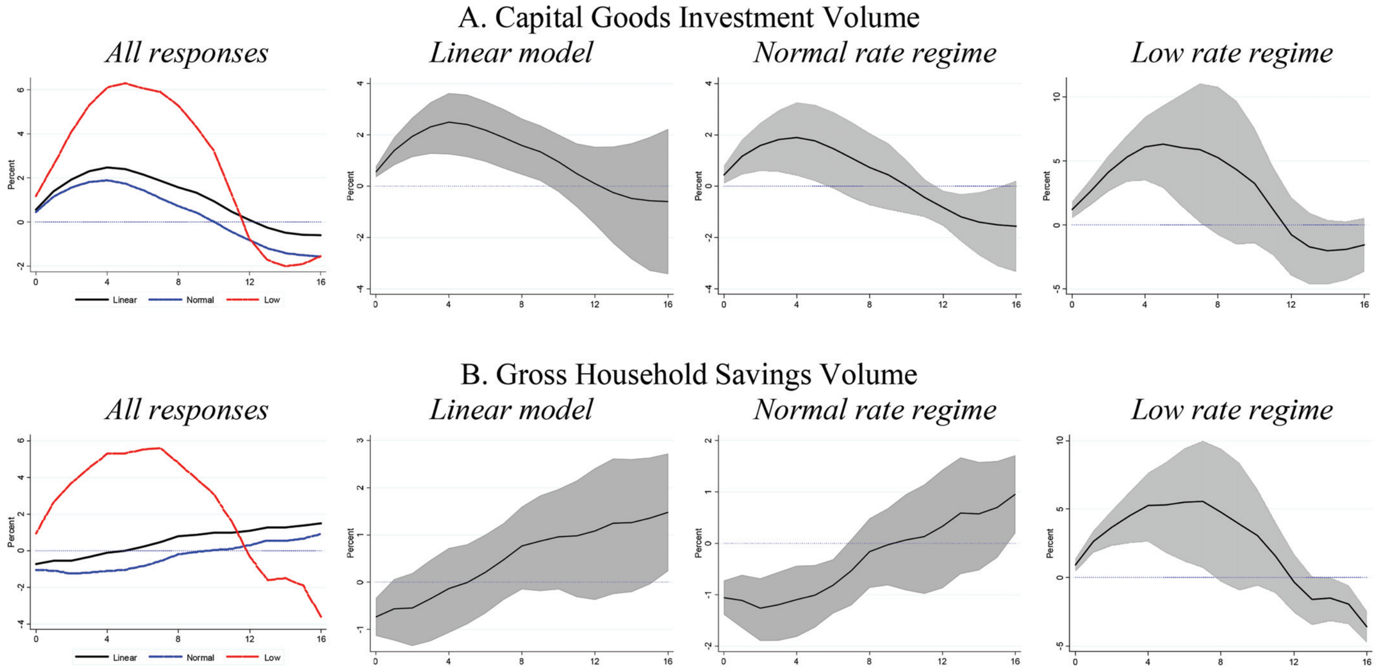
Note: The table reports the median responses in percent (with Newey-West standard errors in parentheses) of capital goods investments and gross household savings in the EA to a one standard deviation expansionary monetary policy shock, in normal (Normal) and low interest rate regimes (Low). The speed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

Table G.2. 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), EA Aggregate

EA	Baseline, $\theta = 7$		$\theta = 3$		$\theta = 10$	
At Horizon $h =$	Normal	Low	Normal	Low	Normal	Low
	Capital Goods Investment Volume					
0	0.617	–0.839	0.591	–1.160	0.597	–0.545
	(0.146)	(0.463)	(0.170)	(0.316)	(0.143)	(0.492)
4	2.409	–2.750	2.419	–2.352	2.362	–2.341
	(0.798)	(1.468)	(0.861)	(1.420)	(0.772)	(1.511)
8	1.134	–1.578	1.094	–0.296	1.133	–1.630
	(1.011)	(1.815)	(1.031)	(2.466)	(0.975)	(1.620)
12	–0.698	2.011	–0.841	1.338	–0.636	2.101
	(0.368)	(1.603)	(0.383)	(1.841)	(0.367)	(1.382)
16	–1.818	7.847	–1.997	3.553	–1.739	10.540
	(1.067)	(1.432)	(1.163)	(2.469)	(1.023)	(2.235)
	Gross Household Savings Volume					
0	–1.027	0.226	–1.196	1.198	–0.969	–0.197
	(0.187)	(1.001)	(0.159)	(0.840)	(0.223)	(0.771)
4	–0.944	3.436	–1.251	4.331	–0.841	2.751
	(0.389)	(1.047)	(0.322)	(1.652)	(0.412)	(0.979)
8	–0.045	2.546	–0.213	3.100	0.022	1.847
	(0.495)	(1.620)	(0.556)	(2.185)	(0.467)	(1.548)
12	0.640	–2.542	0.682	–2.688	0.601	–2.084
	(0.793)	(1.698)	(0.743)	(1.676)	(0.751)	(1.612)
16	1.098	–3.351	1.198	–4.102	1.026	–1.510
	(0.563)	(1.985)	(0.494)	(1.376)	(0.563)	(2.303)

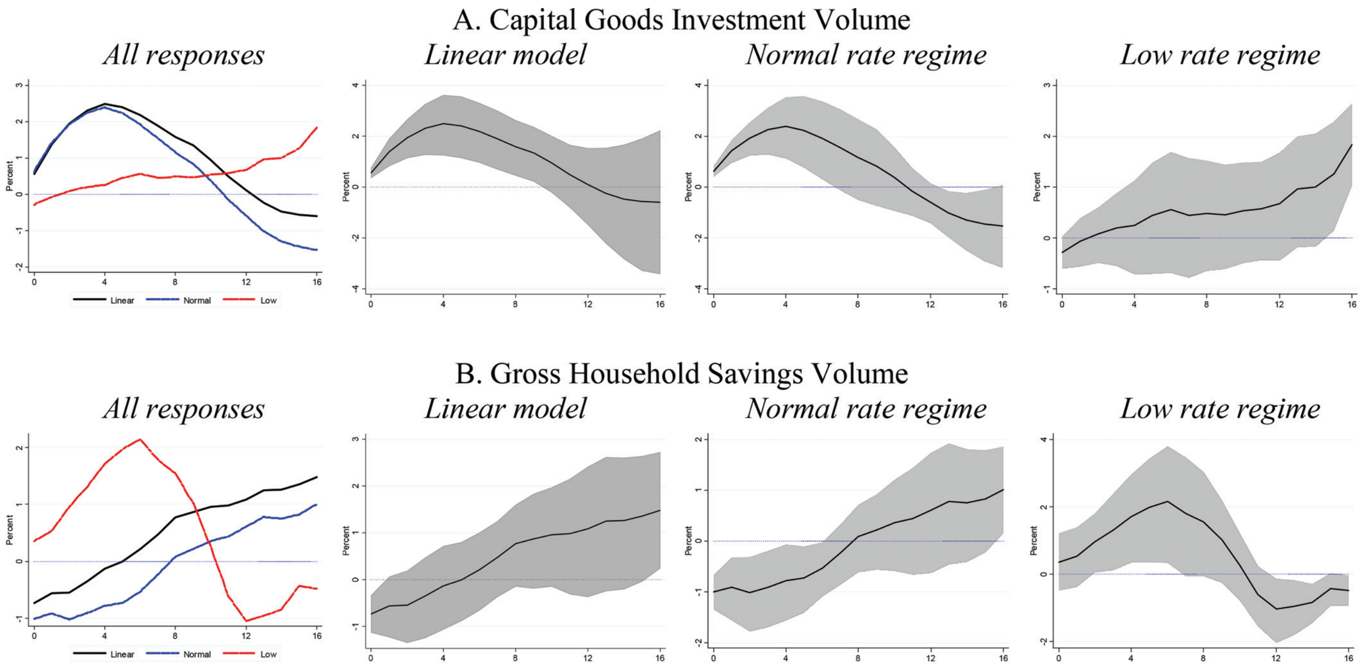
Note: The table reports the median responses in percent (with Newey-West standard errors in parentheses) of capital goods investment and gross household savings in the EA to a one standard deviation expansionary monetary policy shock, in normal (Normal) and low interest rate regimes (Low). The speed of transition c is fixed at –0.1.

Figure G.2. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: State Variable—Short-Term Real Interest Rate, $c = -1.35$



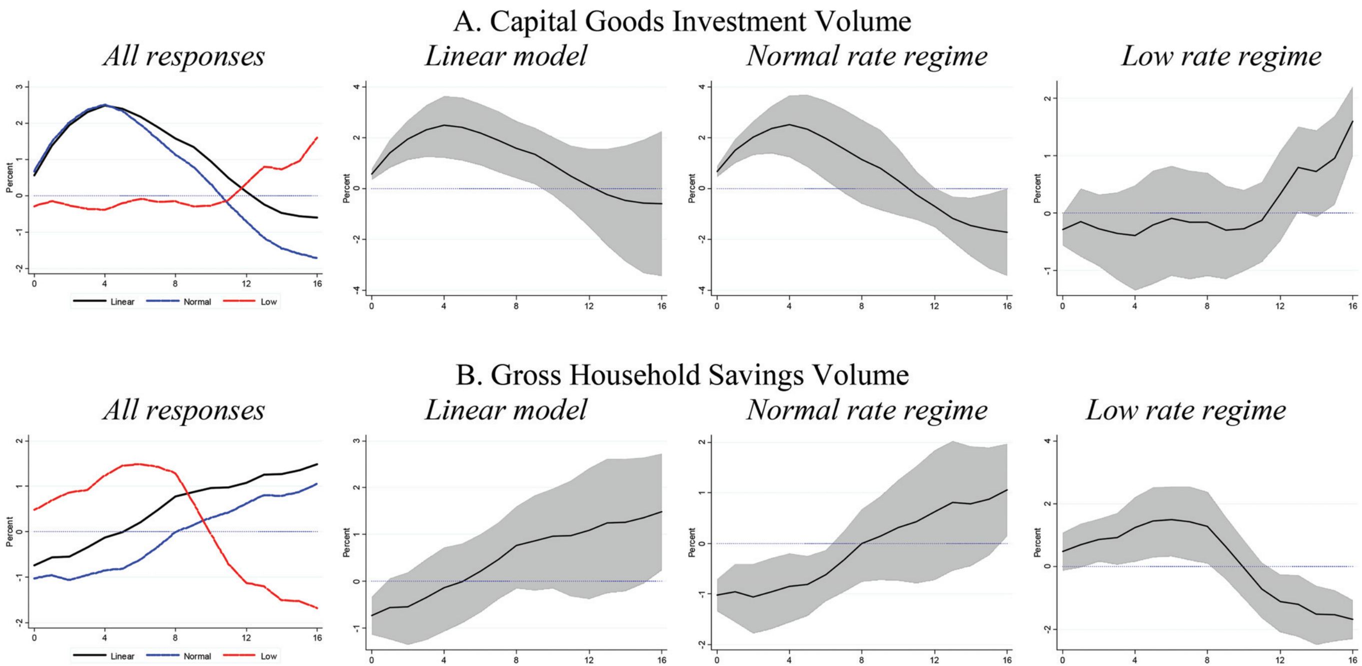
Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure G.3. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: State Variable—Nominal Long-Term Interest Rate, $c = 2.5$



Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

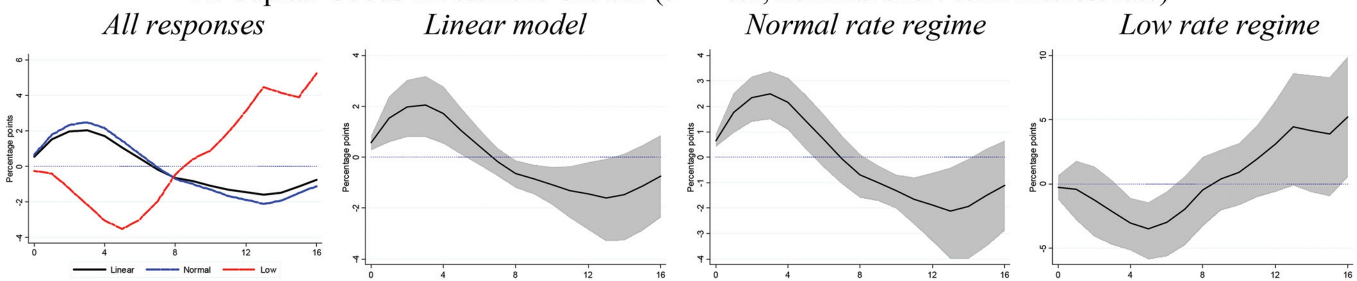
Figure G.4. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: State Variable—Shadow Rate, $c = -1.6$



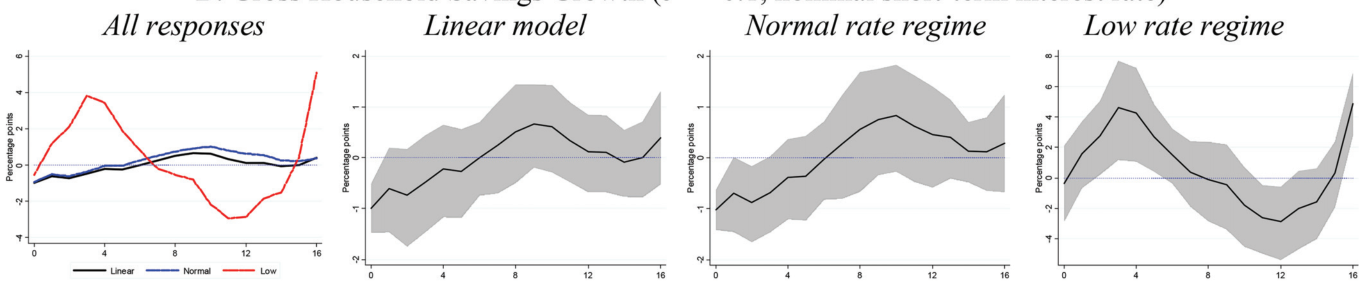
Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure G.5. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA, Robustness Check with Dependent Variables in Log-Differences, EA Aggregate

A. Capital Goods Investment Growth ($c = -0.1$, nominal short-term interest rate)



B. Gross Household Savings Growth ($c = -0.1$, nominal short-term interest rate)

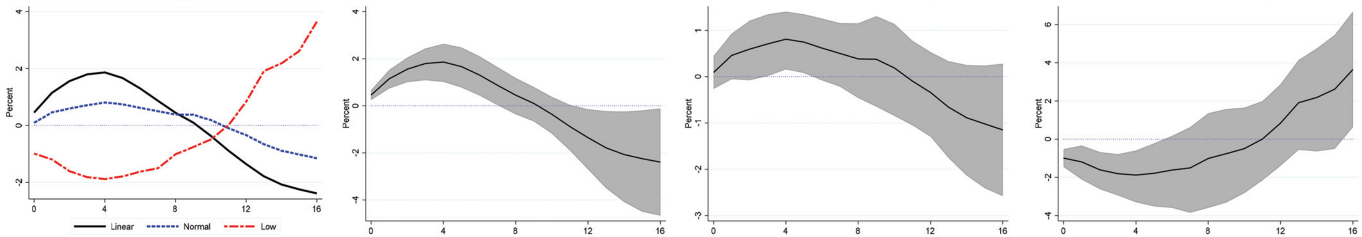


Note: The figure plots smoothed impulse responses of capital goods investments and gross household savings (in log-differences) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure G.6. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: Households' Financial Wealth as Additional Control Variable

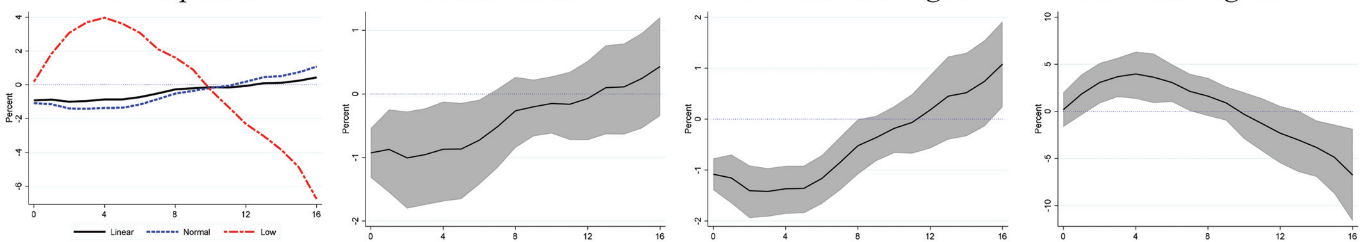
A. Capital Goods Investment Volume ($c = –0.1$, nominal short-term interest rate)

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



B. Gross Household Savings Volume ($c = –0.1$, nominal short-term interest rate)

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

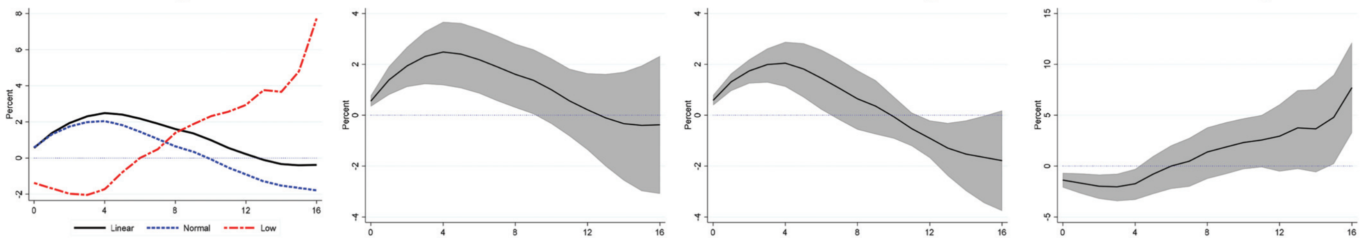


Note: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure G.7. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: Real House Prices as Additional Control Variable

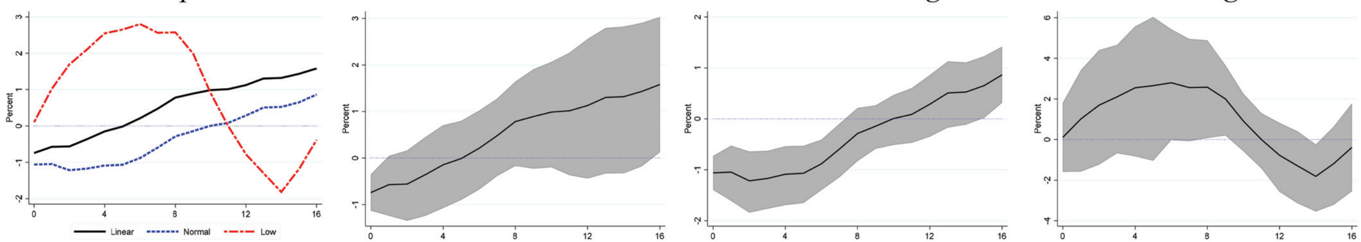
A. Capital Goods Investment Volume ($c = -0.1$, nominal short-term interest rate)

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



B. Gross Household Savings Volume ($c = -0.1$, nominal short-term interest rate)

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

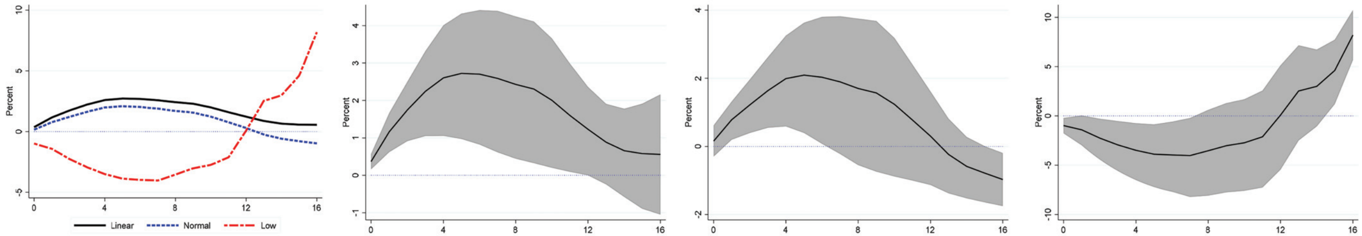


Note: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure G.8. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: Real Stock Prices as Additional Control Variable

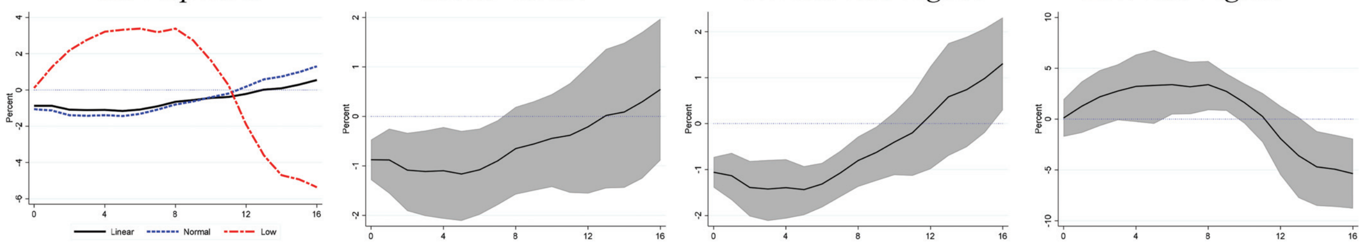
A. Capital Goods Investment Volume ($c = -0.1$, nominal short-term interest rate)

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



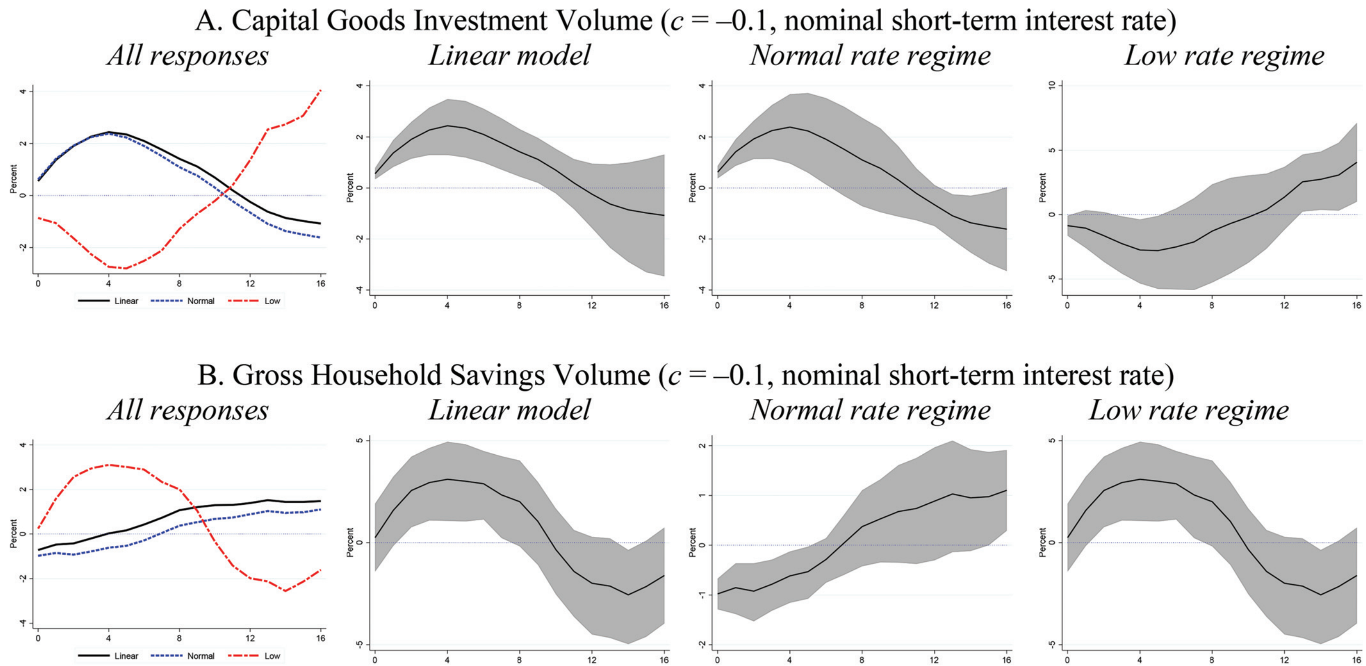
B. Gross Household Savings Volume ($c = -0.1$, nominal short-term interest rate)

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



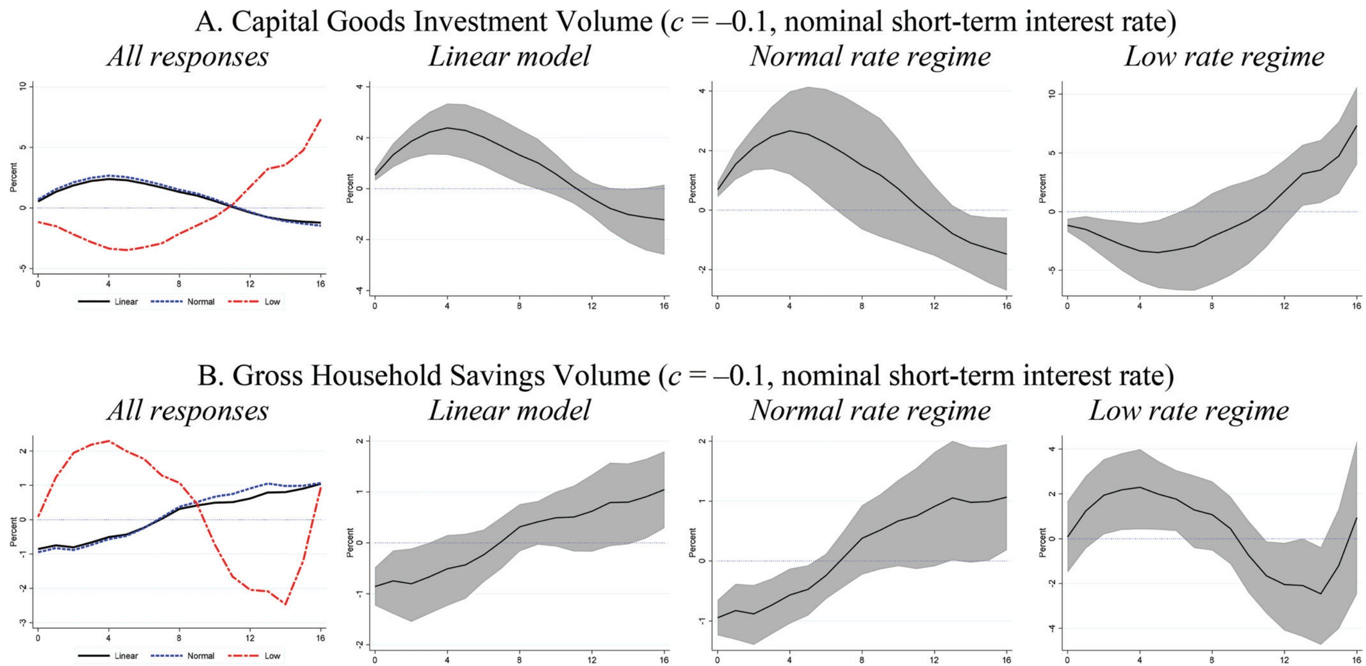
Note: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure G.9. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: Services-to-GDP Ratio as Additional Control Variable



Note: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

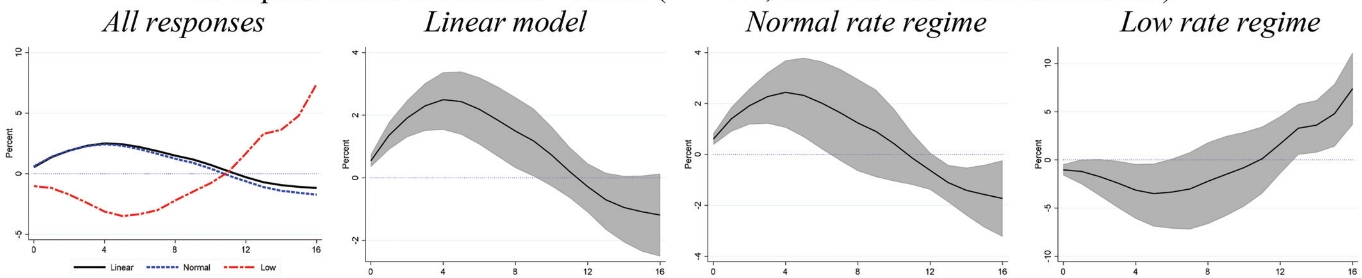
Figure G.10. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: GDP Level as Additional Control Variable (trend included)



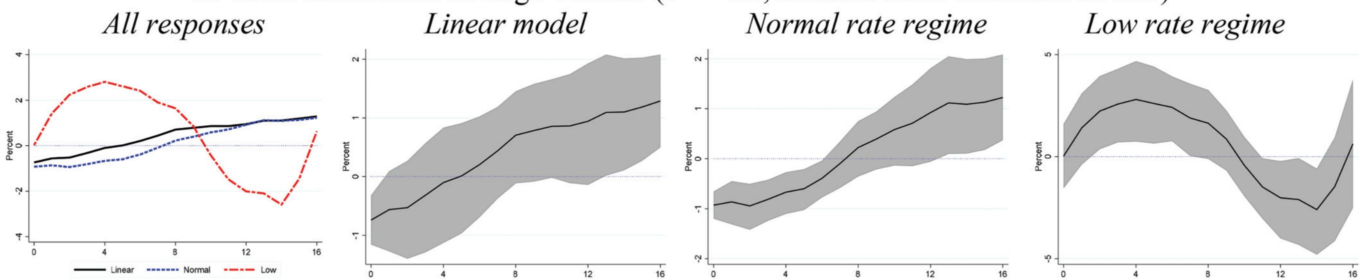
Note: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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 percent confidence interval around the responses (shaded area).

Figure G.11. Impulse Responses of Investments and Savings to an Expansionary Monetary Policy Shock, EA Aggregate, Robustness Check: GDP Level as Additional Control Variable (trend excluded)

A. Capital Goods Investment Volume ($c = -0.1$, nominal short-term interest rate)



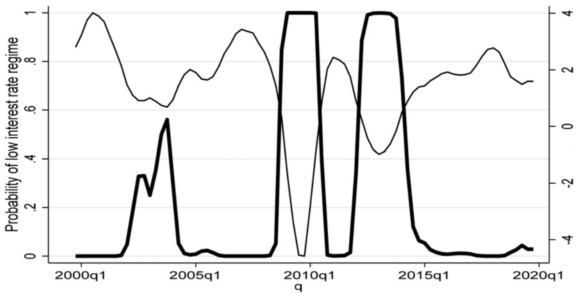
B. Gross Household Savings Volume ($c = -0.1$, nominal short-term interest rate)



Note: The figure plots the smoothed impulse responses of capital goods investments and gross household savings (all in log-levels) to a one st. dev. expansionary monetary policy shock in the EA. In the first column, the solid black line shows the response in the linear model, the blue dashed line shows the response in the normal rate regime, and the red dash-dotted line shows the response 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).

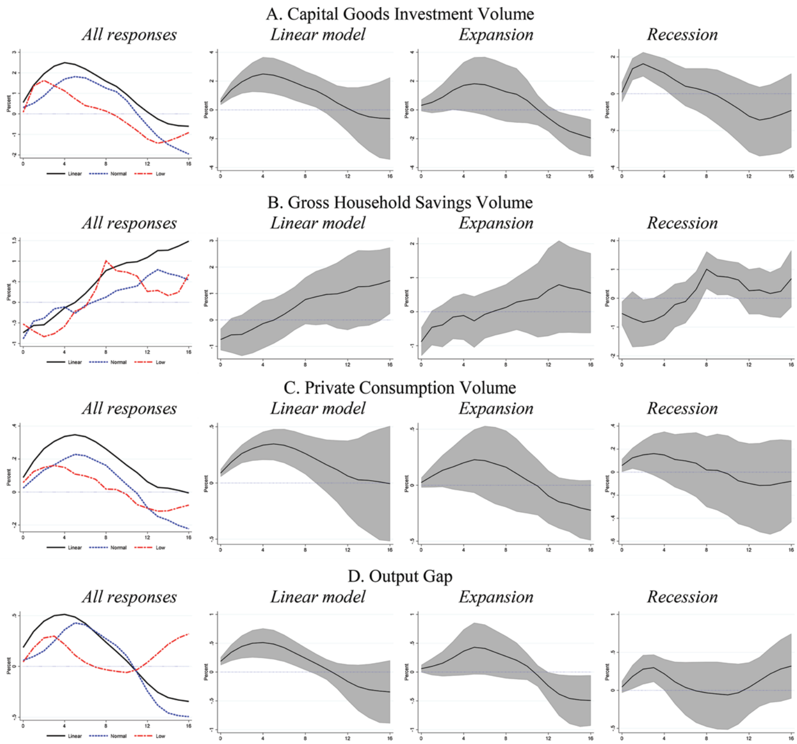
Appendix H

Figure H.1. Probability of Being in Recession, EA Aggregate, State Variable: Four-Quarter Moving Average of GDP Growth, $c = 0.3, \theta = 7$



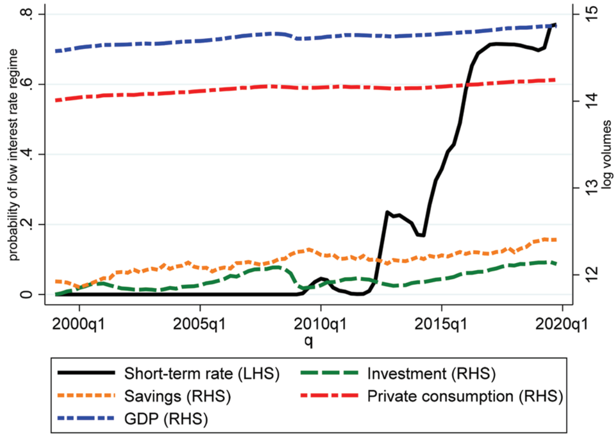
Note: The graph plots the probability of being in a recession (black solid line, left y-axis) together with the corresponding four-quarter moving average of real GDP growth rate used as state variable in the smooth transition function (grey dashed line, right y-axis). The proportion of the sample in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

Figure H.2. Impulse Responses of y_{t+h} to One St. Dev. Expansionary Monetary Policy Shock, EA Aggregate, State Variable: Four-Quarter MA of GDP Growth



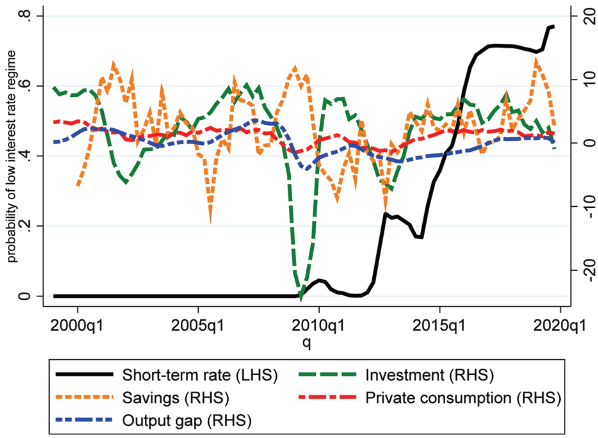
Note: The figure plots the smoothed impulse responses of capital goods investments, gross household savings, private consumption (all in log-levels), and output gap to a one st. dev. expansionary monetary policy shock. In the first column, the solid black line shows the response in the linear model,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

Figure H.3. Probability of Low Interest Rate Regime and Main Response Variables of y_{t+h} in Log-Levels, EA Aggregate, State Variable: Nominal Short-Term Rate



Note: The graph plots the probability of being in the low interest rate regime (black solid line, left y-axis) together with the corresponding response variables (colored/patterned lines, right y-axis), defined as quarterly log-levels of total volumes as in the baseline specification. The proportion of the sample in a low rate regime is set to 20 percent.

Figure H.4. Probability of Low Interest Rate Regime and Main Response Variables of y_{t+h} as Growth Rate/Gap Measure, EA Aggregate, State Variable: Nominal Short-Term Rate



Note: The graph plots the probability of being in the low interest rate regime (black solid line, left y-axis) together with the corresponding response variables (colored/patterned lines, right y-axis) as year-on-year growth rates/the output gap. The proportion of the sample in a low rate regime is set to 20 percent.

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