DNB Working Paper
No. 684 / May 2020

Macroeconomic reversal rate: evidence from a nonlinear IS-curve

Jan Willem van den End, Paul Konietschke, Anna Samarina, Irina Stanga

DeNederlandscheBank
EUROSYSTEEM

Macroeconomic reversal rate: evidence from a nonlinear IS-curve

Jan Willem van den End, Paul Konietschke, Anna Samarina, Irina Stanga*

* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

Working Paper No. 684

May 2020

De Nederlandsche Bank NV
P.O. Box 98
1000 AB AMSTERDAM
The Netherlands

Macroeconomic reversal rate: evidence from a nonlinear IS-curve[1]

Jan Willem van den End[a], Paul Konietschke[b], Anna Samarina[a,c], Irina M. Stanga[a]

[a] De Nederlandsche Bank, the Netherlands

[b] European Central Bank

[C] University of Groningen, the Netherlands

May 2020

Abstract

This paper examines the link between interest rates and expenditures, known as the IS-curve. Specifically, we analyse whether the reaction of spending behaviour to monetary policy changes is different in a low compared to a normal interest rate environment. We estimate the nonlinear IS-curve for the euro area and the five largest euro area countries over the period 1999q2-2019q1 and study whether the IS-curve relationship is regime-dependent. We employ smooth-transition local projections to estimate the impulse responses of the output gap, the growth of consumption, investment, and savings to a contractionary monetary policy shock under normal and low interest rate regimes. Our results point to a possible flattening of the IS-curve, related to substitution effects becoming weaker relative to income effects in a low interest rate regime.

Keywords: IS-curve; monetary policy; low interest rate environment

JEL codes: E21, E22, E43, E52

[1] We thank Maurice Bun, Andrea Colciago, Christiaan Pattipeilohy, Peter van Els, Jakob de Haan and the participants of the research seminar at De Nederlandsche Bank (April 2020) for useful comments and suggestions. We also thank Martin Admiraal for data assistance. The views expressed are those of the authors and do not necessarily reflect the official views of De Nederlandsche Bank, the ECB or the Eurosystem.

1. Introduction

For central banks it is crucial to know whether the sensitivity of the economy to interest rate changes is different in a low interest rate environment. The standard Euler consumption equation (the New Keynesian IS-curve) assumes that a decline of the interest rate leads to intertemporal substitution effects and thereby stimulates spending. According to the forward-looking component of the Euler equation, current consumption also responds to a change in expected future consumption, which in turn is affected by expectations about future monetary policy actions. This is relevant in the current environment when central banks influence expectations of the future interest rate path through forward guidance. An extended period of a low interest rate environment may cause higher savings of firms and households due to negative income effects of low interest rates (Colciago et al., 2019). If these negative income effects dominate substitution effects, expansionary monetary policy may have a contractionary impact. At that juncture monetary policy hits the macroeconomic reversal rate, defined as the interest rate level at which a further loosening of monetary policy becomes counter-productive in stimulating aggregate demand.

This paper examines whether the reaction of spending and investment behaviour to monetary policy shocks is different in a low compared to a normal interest rate environment. We estimate a nonlinear IS-curve for the euro area and the five largest euro area countries and analyse whether the IS-curve relation is regime-dependent. Following the approach of Tenreyro and Thwaites (2016), we employ a smooth transition local projections model and examine the responses of the output gap and different GDP components (consumption, investment, and savings) to a contractionary monetary policy shock under two distinct regimes: normal and low interest rate. We expect that the link between aggregate demand and monetary policy is regime-dependent, as monetary policy transmission may change in a low interest rate environment. This change in transmission can be caused by various factors, such as the trade-off between income and substitution effects, diminishing returns on the bank interest rate margins, or wealth effects.

The substitution and income effects refer to the redistributive channel of monetary policy. This channel works through income, cash flows, and wealth (Borio and Hoffman, 2017). On the one hand, lower interest rates as a result of expansionary monetary policy imply lower interest payments on debt for borrowers (Ampudia et al., 2018). On the other hand, they also reduce interest receipts on deposits for savers and other interest-bearing assets. The strength of the redistributive channel depends on the marginal propensities of consumption and savings, as well as on the type of financial contracts (e.g. whether debt contracts are at adjustable rates).

The persistently low interest rates may impact aggregate demand in several possible ways. First, they encourage precautionary savings. If interest rates are persistently low, negative income effects may become more prevailing. In these circumstances, households are concerned that low returns on savings render their lifetime savings insufficient for retirement. In addition, worries about the value of pensions or life insurance products raise the need for additional savings. Consequently, the substitution effect may become weaker relative to the income effect at very low (positive or negative) levels of interest rates. Guerrón-Quintana and Kuester (2019) show that the income effect of an interest rate cut dominates the intertemporal substitution effect when countries have less generous retirement systems with low government-provided pensions, and the private savings of households become a main source of their retirement consumption.

Second, adverse effects of persistently low interest rates on the economy can also run through the banking sector. If banks' interest rate margins decline and thus their net worth diminishes, the reversal rate can be triggered (Brunnermeier and Koby, 2018). At that point, a lower policy rate can lead to higher instead of lower lending rates and therefore actually reduce lending and investment. The reversal rate used by Brunnermeier and Koby (2018) refers to an earlier stage in the monetary policy transmission (via the banking channel) than the macroeconomic reversal rate channel we define in this paper, which is related to the effects of monetary policy on aggregate demand and savings.

Third, interest rate changes influence aggregate demand through the wealth effects (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, the wealth effects would be stronger in a low rate environment, which could counterbalance the negative income effects on savings.

In addition, changes in nominal interest rates may have different effects on savings and spending than changes in real rates (Borio and Hoffman, 2017). Firms and households may suffer from money illusion, so that their behaviour is influenced by nominal changes (e.g. in cash flows), regardless of changes in the general price level. If that is the case, potential nonlinearities in the IS-curve would apply to nominal, rather than real rates.

The review of the related literature, provided above, suggests that the effect of a low interest rate on the saving and spending behaviour of economic agents depends on the trade-off between the substitution and income effects. This is associated with the modelling of risk aversion in the agent's utility function. In the standard power utility function, the risk aversion parameter is the inverse of the elasticity of intertemporal substitution. This means that if the substitution effect increases, the income effect decreases proportionally. In alternative utility functions, for instance with Epstein-Zin utility, the risk aversion parameter is separated from the elasticity of intertemporal substitution, which allows a calibration of both parameters independently (Epstein and Zin, 1989).

Previous empirical research examines the IS-curve relationship predominantly in a linear setting. To underpin the theoretical relation between spending and monetary policy, a number of studies estimate different specifications of the IS-curve for various countries. In the most common specification, the relation between spending and monetary policy is usually found to be insignificant. When the IS-curve is extended with other (mostly financial) variables, in some cases a significant relation is detected.

Stracca (2010) estimates the IS-curve for output and consumption in a panel of 22 OECD countries over 40 years. He shows that the ex-ante real interest rate enters the IS-curve equation either insignificantly or with the wrong (positive) sign. The results for other potential driving factors (money, house prices, and exchange rate) are mixed. The key finding is that the IS-curve is mainly forward looking – i.e., output (consumption) is driven by expectations of future output (consumption) and the ex-ante real interest rate - and not affected by differences across countries and over time.

In country-by-country OLS estimations of a backward-looking IS-curve for G7 economies over the period 1982q1-1998q4, Goodhart and Hofmann (2005) report that the real interest rate does not have a significant negative effect on the output gap in the baseline model. However, they do find significant effects when the model is extended to include asset prices and monetary aggregates. Similarly, Angeloni and Ehrmann (2007) estimate a backward-looking version of the IS-curve for a panel of 12 euro area countries during 1998-2003 and find that the effect of the real interest rate is significant only at the 10% level.

Ascari et al. (2020) use aggregate U.S. data over 1955q4-2018q1 to estimate the forward-looking IS-curve while controlling for returns of the wealth portfolio, habit formation, and a sizable fraction of hand-to-mouth consumers. Their results differ depending on the particular interest rate used. In the model with the risk-free rate, the Euler equation is flat and consumption does not react to changes in the real interest rate. When the stock market return is used instead of the risk-free rate (i.e., Federal Funds rate) to capture a degree of risk aversion, the slope coefficient of the IS-curve is weakly identified, but significantly greater than zero. In addition, their results are insensitive to using linear versus nonlinear specifications.[2]

[2] Note that the IS-curve 'nonlinearity' considered in Ascari et al. (2020) refers to the nonlinearity due to model parameters and does not account for nonlinearity due to being in different interest rate regimes (normal vs. low). The latter is the specific focus of our paper. Given the long sample period, the results of Ascari et al. (2020) might be sensitive to structural changes over time.

The discussed above studies do not explore whether the relation between spending and interest rates changes in a low rate environment. The closest paper to ours in terms of a research question is Hofmann and Kohlscheen (2017). They use annual data for 31 countries over 1995-2015 to examine the relation between consumption growth and interest rates and account for nonlinearities using piece-wise regressions, which allow the interest rate semi-elasticity to vary across different thresholds of the interest rate. The authors find that consumption growth is linked to nominal rather than real rates. Furthermore, the interest rate semi-elasticity of consumption increases with the level of the interest rate, suggesting that the IS-curve flattens at low rates. However, their approach does not allow identifying distinct interest rate regimes and cannot examine the dynamic reaction of consumption to interest rate changes. Moreover, using interest rates in the IS-curve estimation can be subject to the potential endogeneity problem.

Our paper fills the gap in the literature by explicitly modelling non-linearities in the IS-curve. In contrast to previous studies, we employ smooth transition local projections which allow for the effect of monetary policy shocks on the output gap and GDP components to vary between low and normal interest rate regimes. This analysis can enhance our understanding of monetary policy transmission and effectiveness at the zero lower bound (ZLB).

Our results point to a possible flattening of the IS-curve, which could be explained by the income effects becoming more dominant than the substitution effects at low interest rate levels. In the normal interest rate regime, a contractionary monetary policy shock decreases the output gap, the growth of private consumption and the growth of investment in the short run. However, in the low rate regime the responses of these variables to a contractionary monetary shock become positive, suggesting that substitution effects are weaker relative to income effects in a low interest rate environment. The response of the savings growth provides evidence for potential dominance of the income effects in the low rate regime. While the savings growth increases significantly after a monetary policy tightening in the normal interest rate regime, it drops in the low rate regime. This indicates that in a low interest rate environment further monetary easing could raise the savings growth, which reflects the dominant income effect.

The rest of the paper is structured as follows. Section 2 discusses the research question in the context of a New Keynesian framework. Sections 3 and 4 describe the methodology and data, respectively. Section 5 presents the baseline results, while Section 6 provides the sensitivity analysis. Section 7 concludes with a summary and policy implications.

2. IS-curve in a New Keynesian framework

2.1. Macroeconomic reversal rate

Substitution and income effects in a low interest rate environment can be assessed in a standard representative agent New-Keynesian (RANK) model, which includes the IS-curve as a key equation.[3] In the RANK framework, the ZLB is treated as a nominal friction that can prevent an equilibrium between supply and demand (Eggertson and Woodford, 2003; Benigno and Fornaro, 2018; Galí, 2018). Adverse demand shocks can then lead to a savings surplus, which causes the equilibrium interest rate to fall below zero. When the ZLB is binding, higher uncertainty about future income induces precautionary savings by risk-averse households, leading to a drop in consumption and output as well as a higher probability to fall into a liquidity trap (Krugman, 1998; Basu and Bundick, 2017; Guerrieri and Lorenzoni, 2017). If the central bank is not able to reduce the policy rate below the equilibrium rate due to the ZLB, then a recession follows. 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 (Eggertson, 2010; Christiano et al., 2011). In this framework, a negative equilibrium 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 nominal policy rate into the negative territory does not provide an additional stimulus but actually drives the economy further away from the equilibrium. A negative nominal interest rate works like a macroeconomic reversal rate, which stimulates savings and discourages investments in capital goods (‘investment saturation’). In Palley’s model, investments and savings are driven by nominal interest rates. Agents borrow because they are liquidity constraint (cash-in-advance constraint), for which nominal debt service payments are relevant.

A key role in Palley’s (2019) model is played by non-reproduced assets (NRAs), i.e., assets that are in short supply, such as cash, commodities, land, and monopoly rents. If the marginal nominal return on NRAs is higher than zero (which he assumes to be the lower bound of NRA

[3] Current theoretical literature seems to be shifting to the heterogeneous agents NK (HANK) models. In such models, household heterogeneity on various dimensions implies that there is no aggregate Euler equation and thus no IS-curve of a representative agent, as we know it. The identification of the Euler equation in HANK models depends on whether some agents face a borrowing constraint (‘hand-to-mouth’) or are unconstrained. For a description of HANK models see e.g., Debortoli and Galí (2018), Kaplan et al., (2018), and Ravn and Sterk (2018).

returns[4]), 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 that flow towards NRAs rather than 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 falls if the interest rate decreases. The backward bending part of the demand curve can be associated with negative marginal returns on capital, reflecting a negative natural interest rate. The more negative the marginal returns become, the more investment demand will fall. In Palley's framework, a negative nominal interest rate is also associated with a rise in savings. This situation is reflected in the negatively sloping savings curve in Figure 2, from the point where the interest rate drops below zero. In those conditions, the negative income effect of a negative interest rate (driven by negative nominal returns on bank accounts or diminishing pension wealth) dominates the usual substitution effect.

Figure 1. Investment demand

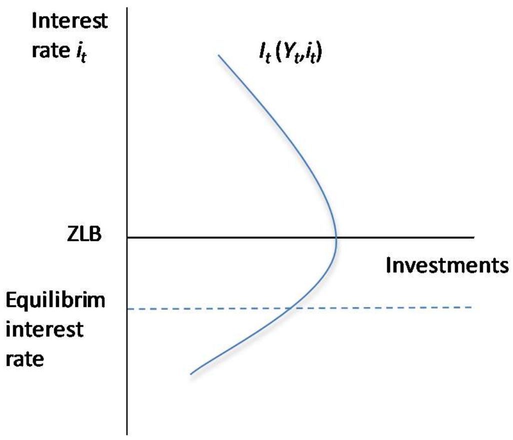
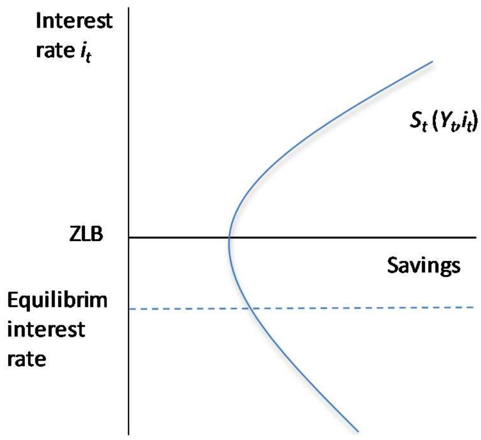


Figure 2. Savings supply



2.2. Financialization

Another view is offered by Bofinger and Ries (2017) who criticize the loanable funds model and assume that if investments in capital goods stay behind, loose monetary conditions stimulate speculative financial activities. Along this channel, low or negative interest rates have adverse

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

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

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

2.3. Implications

The loanable funds and the endogenous money frameworks, discussed above, differ in the assumed drivers behind the low and negative interest rates. In the former the savings surplus is the dominant driver, while in the latter loose monetary policy implies a low interest rate. Nonetheless, in both frameworks the demand for capital goods investment becomes less responsive to a declining interest rate or is being hindered by it. This points to a macroeconomic reversal rate, defined as the interest rate level at which a further loosening of monetary policy becomes ineffective in stimulating aggregate demand.[5] The relative attractiveness of financial

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

activities in a low or negative interest rate environment plays an important role in this mechanism. These insights challenge the IS-curve relationship in the standard NK model.

3. Empirical model

In this section we bring the discussion on the slope of the IS-curve in a low (or negative) interest rate environment to the data, by estimating the IS-curve under different interest rate regimes. The empirical literature estimates the following theoretically derived IS-curve:

$$y_t = \alpha + \beta(i_{t-1} - \pi_t) + \gamma y_{t-1}, \qquad (1)$$

where y_t is output in deviation from the steady state, i_{t-1} is the lagged nominal interest rate, and π_t is consumer price inflation. The parameter of interest β is the elasticity of intertemporal substitution. In addition to examining the output gap, we use subcomponents of output, such as private consumption and investment. We examine income effects by including the savings ratio.

Furthermore, the baseline model is extended with some control variables to account for other channels which affect spending behaviour. Specifically, we include variables measuring households' financial wealth and asset prices to capture wealth effects. This can be an important channel for substitution effects, since low interest rates boost asset prices and subsequently increase the capacity of firms and households to borrow and spend (see in Section 1).

There does not seem to be a consensus in the related empirical literature on which version of the IS-curve one should estimate: a backward-looking or a forward-looking one. Different studies use different versions and arrive at mixed conclusions, while both also produce significant results. Our paper adopts a hybrid approach, explained below.

Equation (1) is a backward-looking IS-curve, as is estimated in some of the empirical studies cited in Section 1. Since agents may be forward looking, some studies also specify forward-looking IS-curves, by including i_t and expected inflation $E_t\pi_{t+1}$ as explanatory variables. Assuming that monetary policy is forward looking, the literature also takes a simultaneity bias into account, usually by an instrumental variable approach (e.g., Fuhrer and Rudebusch, 2004). This 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).

For i_t we use exogenous monetary policy shocks constructed for the euro area by Jarociński and Karadi (2020) (see Section 4 for details). We employ the exogenous shocks in order to avoid the simultaneity problem between interest rates and spending and to circumvent endogeneity issues by looking at the effects of contemporaneous monetary policy shocks. Using the shocks instead of ex-ante or ex-post interest rates implies that our model does not distinguish between backward- or forward-lookingness, but rather offers a hybrid version of the IS-curve 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 - the shocks are based on market interest rates and stock prices, and thereby they capture market expectations (also on inflation). Since the shocks are by definition unanticipated, a typical forward-looking version of the IS-curve is not suitable in our context.

We allow the elasticity of intertemporal substitution β, as well as the other parameters to be different across low and normal interest rate regimes. The state dependence is modelled by a smooth transition local projections model, as in Tenreyro and Thwaites (2016) who adapt the local projections method of Jordà (2005) to estimate the impulse responses of economic variables to monetary policy shocks in recessionary and expansionary regimes. The same approach is applied by Auerbach and Gorodnichenko (2011) and Ramey and Zubary (2014) to analyse the effects of fiscal policy shocks on GDP growth. In our context, the smooth transition model allows β to vary across two regimes as defined by different interest rate levels. Specifically, we estimate the following regression:

$$y_{t+h} = \tau t + F_t\left(\alpha_h^l + \beta_h^l mps_t + \gamma_{h,p}^l L(p) X_t'\right) + (1 - F_t)(\alpha_h^n + \beta_h^n mps_t + \gamma_{h,p}^n L(p) X_t') + \varepsilon_{t+h}, \quad (2)$$

where y_{t+h} is a dependent variable denoting the growth of spending (consumption, investment) and savings, or the output gap in period $t + h$; $h = 0,1,2, \dots H$ is a projection horizon, set to 16 quarters; mps_t is a monetary policy shock, included contemporaneously to derive the policy relevant elasticity; τ is a linear time trend, X_t' is a vector of controls; α_h is a constant, and ε_{t+h} is a projection error term with mean 0. $L(p)$ is a lag polynomial of degree p. As controls, we include the lags of the dependent variable, as it is common in empirical studies of the IS-curve. In a sensitivity analysis we also include other controls. The number of lags p is set to two based on the Schwarz Bayesian information criterion (SBC) for the optimal lag length. As a robustness check, we use the Akaike information criterion (AIC) which indicates that three lags are optimal.

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 normal (n) interest rate regime. The probability of being in either regime is determined by the smooth transition function $F(z_t)$ of an indicator of the state of the economy z_t. For our analysis, $F(z_t)$ is modelled as a logistic function of the interest rate as a state variable, in the following form:

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

where c is a threshold capturing the 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. θ is the speed of transition, measuring how fast the economy switches from a normal interest 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 interest rate regime is distinguished from a normal rate regime by the threshold value c of the interest rate. The threshold is calibrated such that a low interest rate regime occurs in around 20% of the sample.[6] The threshold value c is different for different economies and different measures of the interest rate (e.g., nominal or real, short- or long-term). We check the robustness of our results to various calibrations of this parameter (see Section 6).

The speed of transition between low and normal interest rate regimes (θ) is calibrated by assessing how binary the indicator function is desired to be. Following Auerbach and Gorodnichenko (2011) and Tenreyro and Thwaites (2016), we calibrate rather than estimate the parameters of a 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, estimation of the parameters of function F_t is not common in the related literature.[7]

The local projections model is estimated based on the ordinary least squares (OLS). We account for serial correlation in the error terms by using the Newey-West standard errors.

The estimated coefficients of β_h provide enough information to generate impulse responses of a dependent variable to a contemporaneous monetary policy shock. It shows the $(100{*}\beta_h)$% change in the dependent variable y_{t+h} at horizon h following a 1 p.p. positive (contractionary) monetary policy shock at $t = 0$. We estimate both the linear version of the model (which does not distinguish between interest rate regimes, i.e. F_t = 1) and the state-dependent model (based on the distinction between low and normal interest rate regimes, i.e. 0 < F_t < 1).

The local projections approach has several advantages compared to a typical VAR model. It does not impose specific dynamics on the variables, it does not suffer from the curse of

[6] We follow Auerbach and Gorodnichenko (2011), Ramey and Zubary (2014), and Tenreyro and Thwaites (2016) who define a recession as the worst 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) observations in our sample.

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

dimensionality inherent to VAR models and it can be easily adapted to include nonlinearities (Jordà, 2005; Barnichon and Brownlees, 2019).

As an alternative methodological approach, we used a Bayesian time-varying parameter VAR model (TVP-VAR) which allows estimated parameters to vary over time. Thus, it can serve as a test for nonlinearities by checking whether the responses of variables to a monetary policy shock are time dependent. The findings from this model indeed point to the existence of non-linearities – we detect a change in the estimated impact of a contractionary monetary policy shock on the output gap after the global financial crisis, coinciding with the beginning of a low interest rate regime (results available on request). However, in line with Jordà (2005) we find that the TVP-VAR model is not well suited to capture the distinction between two regimes.

4. Data

Our sample covers quarterly data for the euro area and the five largest euro area countries - Germany, France, Spain, Italy, and the Netherlands - over the period 1999q2-2019q1. For the euro area aggregate and individual euro area countries we use the same monetary policy shock since the euro area member-states share a common monetary policy.

The exogenous monetary policy shocks are taken from Jarociński and Karadi (2020), updated until March 2019.[8] In their model, the authors separate monetary policy shocks from contemporaneous information shocks by analysing the high-frequency co-movement of interest rates and stock prices in a narrow window around policy announcements. Specifically, a monetary policy shock is identified through a negative co-movement between interest rate and stock price changes. The methodology in Jarociński and Karadi (2020) 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 authors' contribution entails using sign restrictions on multiple high-frequency surprises and identifying multiple contemporaneous shocks. Surprises are constructed using intraday variation around ECB policy announcements, in EONIA interest rate swaps with maturities of one month up to two years and the EURO STOXX 50, a market capitalization-weighted stock market index including 50 blue-chip companies.

The interest rate regimes defined in the function F_t are determined by various interest rate measures. In the baseline specification we use nominal and real short-term interest rates. These are 3-months interbank rates, deflated by CPI inflation to construct the real interest rate. In the

[8] We thank Marek Jarociński for sharing the data on monetary policy shocks.

robustness section, we also use a nominal long-term interest rate proxied by 10-year government bond yield, and a nominal bank lending rate (average lending rate on loans to firms and households for euro area countries).

To capture the *substitution effect,* we measure y_t with various components of aggregate demand, such as output gap, total private consumption, consumption of durable goods, and private investments in capital goods (equipment and machinery). To capture the *income effect*, we include the savings ratio (aggregate savings as % of nominal GDP). We are aware that this is not a perfect indictor of income effects, given that savings are not only affected by the interest rate, but also by the wider implications of low interest rates on employment and income as well as by changes in the households' asset portfolio. Hence, only if the savings ratio moves in the direction opposite to what is expected from intertemporal substitution, it signals that adverse income effects may apply.

As additional control variables we include financial assets (total financial assets of households, including pension wealth), stock prices and house prices deflated by CPI inflation. Stock prices are based on the national stock index. To capture global and structural factors explaining the decline in interest rates in recent decades, we include a share of services in GDP.

The time series for macroeconomic variables and interest rates are obtained from the OECD Statistical Database and the Eurostat, complemented with national sources. The output gap is sourced from the Oxford Economics. All variables are transformed into year-on-year growth rates, except for the output gap, interest rates, and monetary policy shocks. All variables are stationary according to the unit root tests (available on request).

5. Results

5.1 Preliminary analysis

Section 5 discusses the baseline results of the linear and state-dependent models. In both models we use only the lagged dependent variable as a control variable.[9] The interest rate regimes in the state-dependent model are defined using the nominal or real short-term interest rate as a state variable.

Figure 1A in the Appendix shows the probability of being in a low or normal interest rate regime (function F_t) for $\theta = 7$ and two threshold values of c, for the nominal short-term rate (a) and the real short-term rate (b) in the euro area. For the euro area, the threshold value of c is equal to 0% for the nominal short-term rate and -1.2% for the real short-term rate. For individual

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

euro area countries the threshold value for the nominal short-term rate is the same as for the euro area aggregate, while thresholds for the real short-term rate vary across countries between -1.55% (the Netherlands) and -0.8% (France). We consider the constructed probabilities in Figure 1A to be plausible probability distributions of the interest rate regimes from an economic point of view. In a sensitivity analysis, we check the robustness of results to using different values of θ and c, as well as different interest rate measures (see Section 6).

Before applying the monetary policy shock of Jarociński and Karadi (2020) in our main analysis, we check how it impacts some standard macroeconomic variables. For this purpose, we estimate a linear model and a state-dependent model using local projections method for the euro area, with real GDP growth, CPI inflation and real stock prices growth as dependent variables in equation (2). The impulse responses are reported in Figure 2A in the Appendix. Median responses are reported with the 90% confidence band.

We find that a 1 p.p. contractionary monetary policy shock reduces GDP growth by 12 p.p. at the trough five quarters after the shock, in a linear model and a normal rate regime. This response stays negative and significant for two years. In a low rate regime the response of GDP growth is insignificant. We find a similar result for CPI inflation – a 1 p.p. contractionary monetary shock implies a drop in inflation by 3 p.p. at the trough three quarters after the shock; this negative effect remains significant for six quarters. Also in this case, the responses are significant in a linear model and a normal rate regime only. Stock prices growth does not respond significantly to a monetary shock in the linear and state-dependent models with the nominal short-term rate used as a state variable. In a normal rate regime, defined by the real short-term rate as a state variable, stock prices growth drops sharply and significantly immediately after the contractionary monetary policy shock and this response remains negative for a year. In a low rate regime the response is reversed; an unexpected monetary contraction leads to a significant increase in stock prices growth in the short run. Generally, the results for a linear model and a normal rate regime are in line with theory and empirical evidence, including the findings of Jarociński and Karadi (2020). Based on this preliminary analysis we conclude that the employed monetary policy shocks are suited for our empirical setting.

5.2 Baseline analysis – empirical approach

According to the substitution effect discussed in Section 2, the response of spending in a normal interest rate regime is expected to be negative, implying that a positive (contractionary) monetary policy shock is associated with a decline in spending growth. The substitution effect might take some time to unfold, in line with the usual lags in monetary transmission. Therefore, we assess the impulse response functions over a medium-term horizon (16 quarters). In a low rate regime we expect that spending growth may behave differently. Based on the discussed literature, we conjecture that the response of spending growth to a contractionary monetary shock in a low rate regime would change the sign, pointing to a reversal of spending behaviour in a low interest rate environment. For savings growth our priors are deduced using a similar reasoning. In a normal rate regime, a contractionary monetary policy shock is expected to increase savings growth, in line with theory. If income effects dominate, the responses of savings growth in a low rate regime are expected to reverse and be negative, implying that a contractionary monetary shock reduces savings growth. We test our conjectures empirically.

Figure 3 shows the impulse responses for the euro area. The results for five euro area countries are displayed in Figures 3A-7A in the Appendix. First, we report the results for the output gap, as in the baseline IS-curve. Since the output gap is inherently subject to measurement issues and is driven by components that are less sensitive to domestic monetary policy (e.g. exports), we also include other spending components as dependent variables, such as the growth of consumption, investment, and savings ratio.

5.3 Substitution effects

The estimated impulse responses point to a significant negative effect of an unexpected monetary tightening on the output gap in the linear model and in the normal rate regime, which holds for the euro area (Figure 3, a-b) and all individual countries (Figures 3A-7A, a-b). In the linear model, a 1 p.p. contractionary monetary policy shock reduces the output gap in the euro area by around 5 p.p. at the trough, which is reached about three quarters after the shock; this response stays negative and significant for one year. Similarly, for individual countries the output gap drops after the contractionary shock and this negative effect remains significant for one-two years. The exception is Italy, where the response is statistically insignificant.

The state-dependent model produces noticeably different responses in a normal and a low rate regime. In the normal interest rate regime, a contractionary monetary shock implies a drop in the output gap by about 7 p.p. at the trough for the euro area. The responses stay negative and significant in all analysed economies for a horizon of 4-8 quarters after the shock. This result is in line with theory and empirical studies on the effect of monetary policy on aggregate demand. It provides evidence for the existence of substitution effects.

In the low rate regime, the response of the output gap is insignificant in the euro area. For individual countries in some specifications (conditional on the state variable) the responses are significant with a reversed, positive sign. A contractionary monetary shock increases the output gap in a low rate regime, with the peak effect ranging between 10 p.p. (France) and 35 p.p. (Spain). While for most countries this effect is short-lived, in Spain the positive response stays significant for the entire projection horizon of four years in the low rate regime defined by the real short-term interest rate. These results suggest that in a low interest rate environment the substitution effect becomes weaker relative to the income effect.

Similar results are found for the responses of private consumption growth (see Figure 3 (c-d) for the euro area and Figures 3A-7A (c-d) for individual countries). Consumption growth decreases significantly after a contractionary monetary policy shock in the linear model (except for Italy and France), by 2 p.p. at the trough for the euro area. The responses vary between the normal and low interest rate regimes. In the normal rate regime, a contractionary monetary shock reduces consumption growth in the euro area by 4 p.p. two quarters after the shock; this response remains negative and significant for six quarters. For individual countries, the estimated drop in the growth of consumption is by 5-10 p.p. at the trough; this effects stays significant on average for four-six quarters after the shock.

In contrast, in the low interest rate regime private consumption growth increases after a contractionary monetary shock. For the euro area, Germany, and France we find a significant positive response of consumption growth to a contractionary shock in the low rate regime defined by the nominal short-term interest rate, and for Italy and France in the low rate regime defined by the real interest rate. The magnitude of the response at the peak is 8 p.p. for the euro area; this positive effect stays significant for one-two years.[10]

Overall, these results suggest that, while in a normal rate regime the behaviour of consumption growth supports the substitution effect in the IS-curve, in a low rate regime consumption may behave in the opposite way. This is in line with, e.g., Guerrieri and Lorenzoni (2017) who derive theoretically that under ZLB on interest rates consumption and output may drop. This implies that in a low interest rate environment further monetary easing (negative monetary policy shock) might not stimulate private consumption growth, but even reduce it.

The responses of capital goods investment growth to a contractionary monetary policy shock are significant and negative for all economies in the linear model, except Italy (see Figure 3 (e-f) and Figures 3A-7A (e-f)). It implies that unexpected monetary tightening is associated with a decline in investment growth. This effect is substantial in terms of the magnitude of the response, with the growth of investment dropping by around 35 p.p. at the trough in the euro area. The negative response remains significant and lasts for 4-6 quarters after the shock.

[10] As an alternative, we examine the consumption growth of durable goods in individual euro area countries. The impulse responses of that variable are similar to the ones for total consumption growth (results available on request).

There is a significant difference in the responses of investment growth for the two interest rate regimes. In the normal rate regime, a contractionary monetary policy shock strongly reduces investment growth in the euro area by 40 p.p. at the trough, with this effect lasting for six quarters after the shock. Similar responses are reported for the individual countries, albeit of varying magnitudes. In a low rate regime, the responses are reversed for the euro area and most individual countries. The investment growth increases significantly after a contractionary monetary shock in the euro area (by 50 p.p. at the trough).[11] This result is in line with previous studies (e.g., Bofinger and Ries, 2017; Palley, 2019) pointing to the reversal of investment behaviour in a low interest rate environment.

The first column of graphs in Figures 3 and 3A-7A (Appendix) show the median impulse responses of the output gap, consumption growth, and capital investment growth, based on the linear and state-dependent models. These graphs indicate that the responses in the normal and low interest rate regimes are noticeably different. To evaluate whether the responses are statistically different between the two regimes, 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 the clustered standard errors, used during the estimation.[12] The results of the test (see Table 1A in the Appendix) indicate that the median responses are statistically significantly different between the normal and low interest rate regimes for all analysed dependent variables.

5.4 Income effects

This section discusses how savings growth responds to a monetary policy shock in the two regimes. These responses provide strong evidence for the income effect becoming stronger relative to the substitution effect in the IS-curve in the low interest rate regime (see Figure 3 (g-h) and Figures 3A-7A (g-h)). In the linear model and in the normal interest rate regime of a state-dependent model, savings growth significantly increases after a contractionary monetary policy shock. This holds for the euro area, Spain, and the Netherlands, while the responses are insignificant for Germany, France, and Italy. A 1 p.p. contractionary shock in the euro area implies the peak increase in the savings growth by 20 p.p. three quarters after the shock. This effect remains positive for about six quarters and afterwards gradually dies out. In the low rate regime, savings growth significantly drops after a contractionary monetary policy shock. This

[11] In Germany and France the effects are found when the low rate regime is defined by the nominal short-term interest rate, while in Italy and Spain by the real short-term rate. The responses are insignificant in the Netherlands.
[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.

result can be noticed for the euro area, Germany, France, and Spain and these responses remain negative and significant for about two years. In case of the euro area, the magnitude of the negative response in a low rate regime is larger than the magnitude of the positive response in a normal rate regime, reaching 50 p.p. at the trough, about three quarters after the shock.

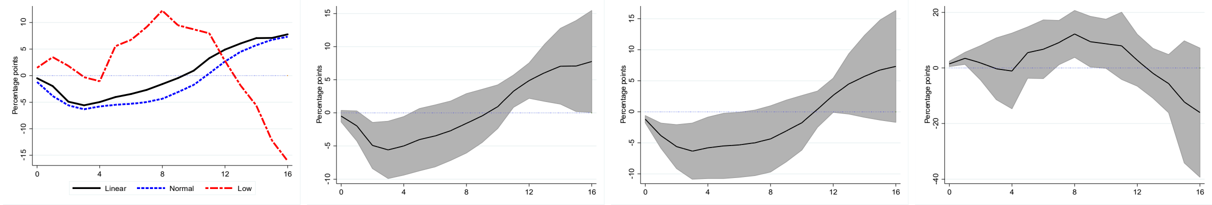
These findings are in line with the Palley's (2019) model and indicate that in a low interest rate environment further monetary easing would raise savings growth, which reflects that the income effect becomes stronger relative to the substitution effect.

The impulse responses of the savings ratio growth to a contractionary monetary shock in the euro area in the normal and low interest rate regimes are also considerably different from each other. A joint Chi-squared test confirms that the response of the savings ratio growth is also statistically significantly different in two regimes (see Table 1A in the Appendix).

Figure 1. Impulse responses of y_{t+h} to 1 p.p. contractionary monetary policy shock, euro area

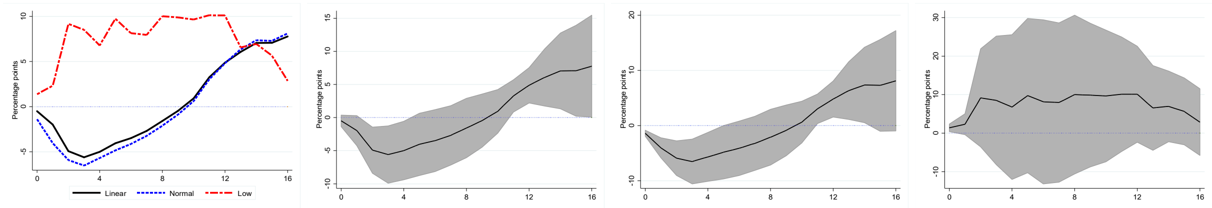
a) Output gap (c=0, nominal short-term interest rate)

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



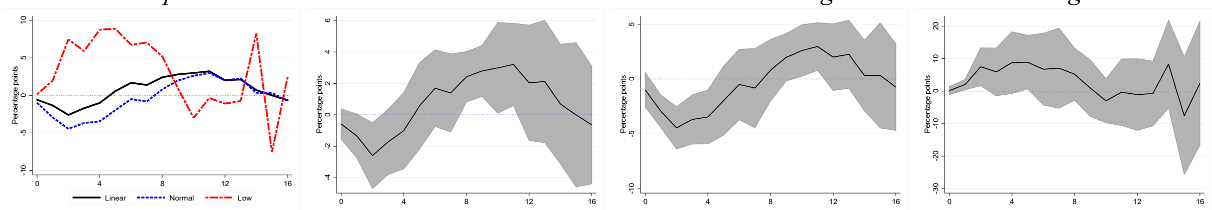
b) Output gap (c=-1.2, real short-term interest rate)

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



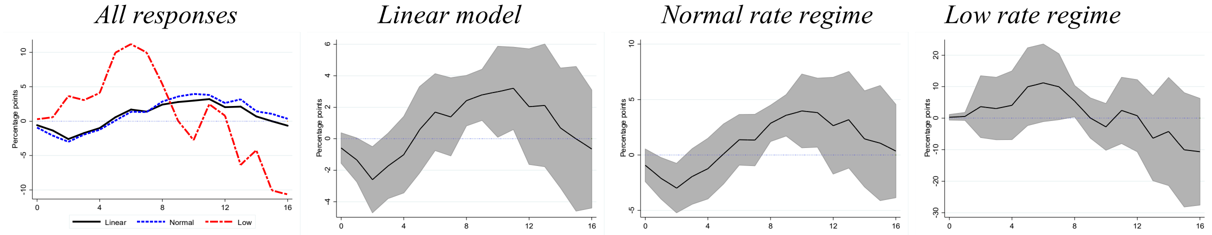
c) Consumption growth (c=0, nominal short-term interest rate)

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



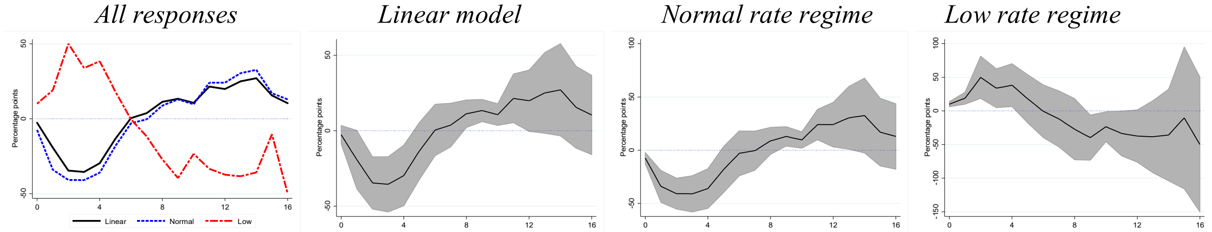
d) Consumption growth (c=-1.2, real short-term interest rate)

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



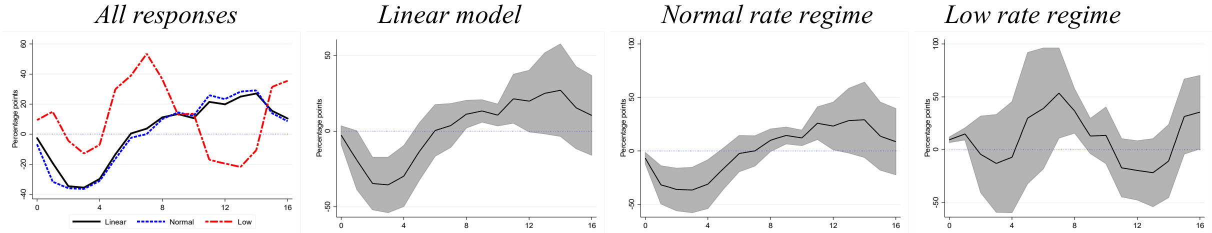
e) Capital goods investment growth (c=0, nominal short-term interest rate)

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



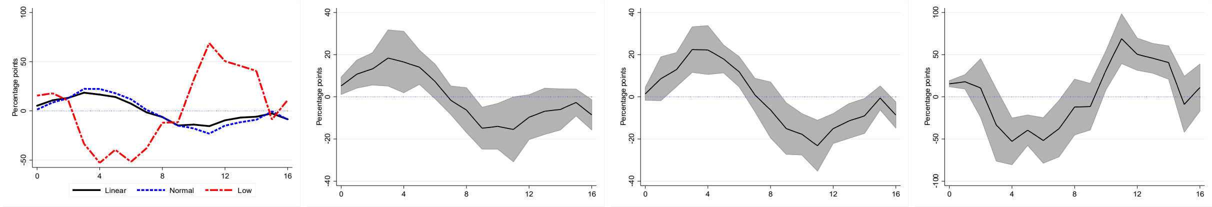
f) Capital goods investment growth (c=-1.2, real short-term interest rate)

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



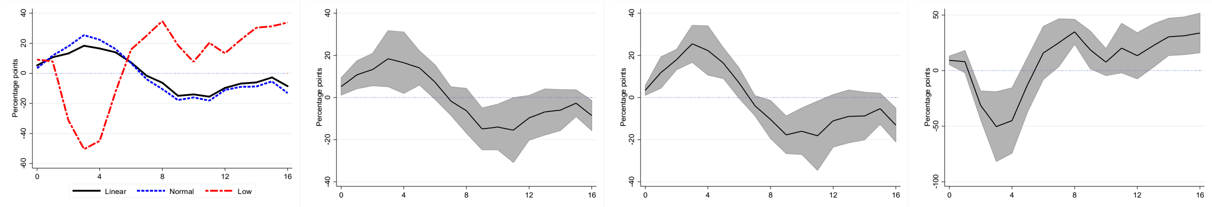
g) Savings ratio growth (c=0, nominal short-term interest rate)

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



h) Savings ratio growth (c=-1.2, real short-term interest rate)

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



Notes: The figure plots impulse responses of the output gap, private consumption growth, capital goods investment growth, and savings ratio growth to a 1 percentage point positive (contractionary) monetary policy shock. In the first column, the solid black line shows the response in a linear, state-independent model, the blue dashed line shows the response in a normal interest rate regime, and the red dash-dotted line shows the response in a low rate regime. The second, third, and fourth columns show the responses in a linear model, normal, and low interest rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

6. Sensitivity analysis

6.1 Lag length and control variables

In this section we test the sensitivity of our results to the choice of lags for dependent and shock variables as well as to the inclusion of additional control variables (all results are available on request). In the baseline specification we include two lags of the dependent variable, as indicated by the SBC. The AIC suggests instead to use three lags. Note that the AIC tends to overidentify the models by indicating more lags than other information criteria, especially for small samples. As a robustness check, we re-estimate all models with three lags for the dependent variable; the results are not qualitatively affected by this modification.

Next, 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 or the second lag of the shock to account for possible delays in the monetary policy transmission. The main findings are not affected by these changes. The results also hold when we include one or two lags of a monetary policy shock as additional control variables.

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

We find that the responses in the models including the growth in financial wealth or asset prices remain largely unchanged. Adding financial wealth and house price growth as control variables makes the responses of personal consumption growth in the euro area less significant in the linear model and the normal rate regime, but more significant in the low rate regime.

The inclusion of the services ratio does not affect our baseline outcomes; these hold across all analysed economies, dependent variables, and interest rate measures in a smooth transition function. Overall, the main conclusions remain broadly unchanged, which suggests that the findings of the baseline model are robust.

6.2 Parameters in a smooth transition function

We examine the robustness of our findings to modifications of the calibrated parameters in the smooth transition function $F(z_t)$, namely the threshold values c of the state variable and the speed of transition θ. The robustness checks are applied to the baseline model (equation 2) for the euro area with the output gap as a dependent variable (results for other dependent variables and for individual countries are available on request).

First, we experiment with the threshold values c for the nominal short-term interest rate as a state variable, keeping the speed of transition θ fixed at 7. We calibrate the alternative threshold values in such a way that a low interest rate regime occurs in around 30%, 40%, and 50% proportion of the sample. This corresponds to the threshold values c of the nominal short-term rate equal to 0.25%, 0.8%, and 1.5%, respectively. Our highest calibrated threshold of 1.5% is close to the one used by Claessens et al. (2018), who classify a country as being in a "low" rate environment when its three-month interest rate is below or equal to 1.25%. In our sample for the euro area over the period 1999q2-2019q1, this occurs in around 45% of observations. Thus, using the threshold value of 1.5% occurring for 50% of the sample, we can identify the low rate regime as understood by related studies.

We estimate impulse responses of the output gap for alternative threshold values c in a smooth transition function, next to the baseline value of 0% for the nominal short-term interest rate (see Table 2A in the Appendix). The results for the low rate regime are more sensitive to changes in c than the results for the normal regime, but largely in line with the main findings. In general, the estimated responses become smaller in magnitude as we increase the threshold, although the sign of responses does not change. Raising the threshold implies that the low interest 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 the normal and low rate regimes on the response of aggregate demand to monetary policy shocks.[13] While this does not change the sample size, the effect on standard errors of the pointwise coefficient estimates of the impulse response is similar to increased sample uncertainty.[14] Nevertheless, these modifications do not alter our main conclusions.

Next, we probe the robustness of our results to using different values of θ, which captures the speed of transition between the interest rate regimes. In the baseline specification θ is set to 7. As alternatives we set θ equal to 3 and 10. The higher the value of θ, the more binary are the regime probabilities and the faster is the transition from one regime to the other. The sensitivity to different values of θ is tested with the nominal short-term interest rate used as a state variable, keeping the threshold value c fixed at 0% (see Table 3A in the Appendix). The impulse responses in the normal rate regime are slightly less significant compared to the baseline when the speed of transition is slower, i.e. $\theta=3$, while the responses in the low rate regime are stronger and more significant when $\theta=10$ and the transition from a normal to a low rate regime is faster. Overall, modifying the speed of transition in our model does not affect our main findings.

6.3 State variables in a smooth transition function

We use two alternative measures of the state variable z_t in a smooth transition function, namely the long-term interest rate (proxied by a ten-year government bond yield) and the bank lending interest rate. The threshold value c for these interest rates is calibrated so that a low interest rate regime occurs in around 20% of the sample, similar to the calibration used for the short-term rate in the baseline model. For the euro area, this threshold is equal to 1.3% for the long-term interest rate and 2% for the lending rate. For individual euro area countries these thresholds vary by country. The speed of transition θ is fixed at 7 as in the baseline specification.

Figure 1A in the Appendix shows the probability of being in a low or normal rate regime for the nominal long-term interest rate (c) and for the nominal lending rate (d) as a state variable, in the euro area. The timing of a low rate regime derived using these interest rates coincides

---

[13] Note that this is not equivalent to testing the sensitivity of the 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 low rate regime.

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

partially with the timing of a low rate regime based on the nominal short-term rate. The probability of being in a low rate regime based on long-term or lending rates takes non-zero values only after 2015q1, while this probability for the nominal short-term rate indicates the start of transition to a low rate regime to be a couple of years earlier. This could be due to a slower decline of long-term and lending rates over time compared to the observed dynamics for short-term rates in the euro area.

The impulse responses of the output gap for the euro area from smooth transition local projections with these alternative state variables are shown in Figure 8A in the Appendix (results for other dependent variables and individual countries are available on request). The estimated responses of the output gap to a 1 p.p. contractionary monetary policy shock, based on the lending and long-term interest rates as state variables, are qualitatively similar to the baseline results for the short-term rate as a state variable, in both regimes. This holds for all dependent variables and analysed countries. Thus, our conclusions are robust to the choice of the state variable in the smooth transition function.

7. Conclusion

This paper examines the nonlinearities in the IS-curve relation, by comparing the reaction of spending and saving behaviour to monetary policy shocks in a low versus a normal interest rate environment. We employ smooth-transition local projections to estimate the impulse responses of different GDP components to a contractionary monetary policy shock in the euro area and the five largest euro area countries over the period 1999q2-2019q1 under two distinct regimes: normal and low interest rate. Our results point to a possible flattening of the IS-curve, related to the income effects becoming stronger relative to the substitution effects in a low rate regime.

Following a contractionary monetary policy shock, the output gap, consumption growth and the growth of investment spending significantly decrease in the normal rate regime. In contrast, in the low rate regime the responses of these variables reverse signs and become positive and significant in most cases. This suggests that the substitution effects become less strong relative to the income effect in a low rate environment.

The responses of the change in savings ratio support the evidence for stronger income effects in a low rate regime. While the savings ratio increases after a contractionary monetary policy shock in the normal interest rate regime, it drops in a low rate regime. This indicates that in a low interest rate environment further monetary policy easing raises savings, which reflects that the income effect becomes stronger relative to the substitution effect.

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

The existence of such nonlinearities in the IS-curve imply that monetary policy conduct may be limited in certain macro-economic conditions. The persistence of low interest rate levels is a likely determinant of the interest sensitivity of aggregate demand. The longer the interest rates remain low, the higher the likelihood of a change in the behaviour of economic agents and their expectations. Under such conditions, it is increasingly likely that income effects become stronger relative to substitution effects, thereby limiting the effectiveness of monetary policy.

References

Angeloni, I., A. Kashyap and B. Mojon (2003). Monetary policy transmission in the Euro Area, Cambridge: Cambridge University Press.

Angeloni, I. and M. Ehrmann (2007). Euro area inflation differentials. *The B.E. Journal of Macroeconomics,* 7(1), 1-36.

Ampudia, M., D. Georgarakos, J. Slacalek, O. Tristani, P. Vermeulen, and G. Violante (2018). Monetary policy and household inequality. ECB Working Paper 2170, European Central Bank, Frankfurt am Mein.

Ascari, G., L. Magnusson, and S. Mavroeidis (2020). Empirical evidence on the Euler equation for consumption in the U.S., *Journal of Monetary Economics*, forthcoming.

Auclert, A. (2019). Monetary policy and the redistribution channel. *American Economic Review*, 109(6), 2333-2367.

Auerbach, A.J. and Y. Gorodnichenko (2011). Fiscal multipliers in recession and expansion. NBER Working Papers 17477, National Bureau of Economic Research, Cambridge MA.

Barnichon, R. and C. Brownlees (2019). Impulse response estimation by smooth local projections. *The Review of Economics and Statistics*, 101(3), 522-530.

Basu, S., and B. Bundick (2017). Uncertainty shocks in a model of effective demand. *Econometrica,* 85(3), 937-958.

Benigno, G. and L. Fornaro (2018). Stagnation traps. *Review of Economic Studies*, 85(3), 1425-1470.

Bofinger, P. and M. Ries (2017). Excess saving and low interest rates: theory and empirical evidence, CEPR Discussion papers 12111, Centre for Economic Policy Research, London.

Borio, C., P. Disyatat, and P. Rungcharoenkitkul (2019). What anchors for the natural rate of interest? BIS Working Paper 777, Bank for International Settlements, Basel.

Brunnermeier, M.K. and Y. Koby (2018). The reversal interest rate. NBER Working Papers 25406, National Bureau of Economic Research, Cambridge MA.

Brunnermeier, M.K. and Y. Sannikov (2012). Redistributive monetary policy. Proceedings - Economic Policy Symposium - Jackson Hole, Federal Reserve Bank of Kansas City, 331-384.

Borio, B. and B. Hoffman (2017). Is monetary policy less effective when interest rates are persistently low? BIS Working Paper 628, Bank for International Settlements, Basel.

Christiano, L., M. Eichenbaum, and S. Rebelo (2011). When is the government spending multiplier large? *Journal of Political Economy*, 119(1), 78-121.

Claessens, S., N. Coleman, and M. Donnelly (2018). "Low-For-Long" interest rates and banks' interest margins and profitability: Cross-country evidence. *Journal of Financial Intermediation,* 35(A), 1-16.

Colciago, A., A. Samarina, and J. de Haan (2019). Central bank policies and income and wealth inequality: a survey. *Journal of Economic Surveys*, 33(4), 1199-1231.

Debortoli, D. and J. Galí (2018). Monetary policy with heterogeneous agents: insights from TANK models. Economics Working Papers 1686, Department of Economics and Business, Universitat Pompeu Fabra, Barcelona.

Eggertsson, G. (2010). What fiscal policy is effective at zero interest rates? *NBER Macroeconomics Annual,* 25, 59-112.

Eggertson, G.B. and M. Woodford (2003). The Zero bound on interest rates and optimal monetary policy. *Brookings Papers on Economic Activity*, 1, 139-211.

Epstein, L.G. and S.E. Zin (1989). Substitution, risk aversion, and the temporal behavior of consumption and asset returns: a theoretical framework. *Econometrica*, 57(4), 937-969.

Fuhrer, J.C. and G.D. Rudebusch (2004). Estimating the Euler equation for output. *Journal of Monetary Economics*, 51(6), 1133-1153.

Galesi, A. and O. Rachedi (2019). Services deepening and the transmission of monetary policy. *Journal of the European Economic Association,* 17(4), 1261-1293.

Galí, J. (2018). The State of New Keynesian economics: a partial assessment. *Journal of Economic Perspectives,* 32(3), 87-112.

Gertler, M. and P. Karadi (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics*, 7, 44-76.

Goodhart, C. and B. Hofmann (2005). The IS curve and the transmission of monetary policy: is there a puzzle? *Applied Economics*, 37(1), 29-36.

Gornemann, N., K. Kuester, and M. Nakajima (2016). Doves for the rich, hawks for the poor? Distributional consequences of monetary policy. CEPR Discussion Papers 11233, Centre for Economic Policy Research, London.

Granger, C. W. J. and T. Teräsvirta (1993). Modelling non-linear economic relationships.

Oxford University Press.

Guerrieri, V. and G. Lorenzoni (2017). Credit crises, precautionary savings, and the liquidity trap. *The Quarterly Journal of Economics*, 132(3), 1427-1467.

Guerrón-Quintana, P. and K. Kuester (2019). The dark side of low(er) interest rates. Federal Reserve Bank of San Francisco, mimeo.

Havranek, T. and M. Rusnak (2013). Transmission lags of monetary policy: a meta-analysis. *International Journal of Central Banking*, 9(4), 39-76.

Herrendorf, B., R. Rogerson, and Á. Valentinyi (2013). Two perspectives on preferences and structural transformation. *American Economic Review*, 103(7), 2752-2789.

Hofmann, B. and E. Kohlscheen (2017). Consumption and interest rates: a cross-country analysis, unpublished manuscript, Bank for International Settlements, Basel.

Jarociński, M. and B. Maćkowiak (2018). Monetary-fiscal interactions and the euro area's malaise. *Journal of International Economics*, 112(C), 251-266.

Jarociński, M. and P. Karadi (2020). Deconstructing monetary policy surprises - the role of information shocks. *American Economic Journal: Macroeconomics*, 12(2), 1-43.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American Economic Review*, 95 (1), 161-182.

Kaplan, G., B. Moll, and G.L. Violante (2018). Monetary policy according to HANK. *American Economic Review*, 108 (3), 697-743.

Kleibergen, F. and S. Mavroeidis (2009). Weak instrument robust tests in GMM and the New Keynesian Phillips curve. *Journal of Business and Economic Statistics*, 27(3), 293-311.

Krugman, P.R. (1998). It's baaack: Japan's slump and the return of the liquidity trap. *Brookings Papers on Economic Activity*, 29(2), 137-206.

Mertens, K. and M.O. Ravn (2013). The dynamic effects of personal and corporate income tax changes in the United States. *American Economic Review*, 103, 1212-1247.

Onaran, O., E. Stockhammer, and L. Grafl (2011). Financialization, income distribution, and aggregate demand in the US. *Cambridge Journal of Economics*, 35(4), 637-666.

Palley, T.I. (2019). The fallacy of the natural rate of interest and zero lower bound economics: why negative interest rates may not remedy Keynesian unemployment, *Review of Keynesian Economics*, 7(2), 151-170.

Ramey, V.A. and S. Zubary (2014). Government spending multipliers in good times and in bad: evidence from U.S. historical data. NBER Working Papers 20719, National Bureau of Economic Research, Cambridge MA.

Ravn, M. O. and V. Sterk (2018). Macroeconomic fluctuations with HANK & SAM: an analytical approach, mimeo, University College London.

Schmitt-Grohé, S., and M. Uribe (2017). Liquidity traps and jobless recoveries. *American Economic Journal: Macroeconomics*, 9(1), 165-204.

Shin, H. S. (2012). Global banking glut and loan risk premium. *IMF Economic Review*, 60(2), 155-192.

Stock, J. H. and M.W. Watson (2018). Identification and estimation of dynamic causal effects in macroeconomics using external instruments. NBER Working Papers No. 24216, National Bureau of Economic Research, Cambridge MA.

Stracca, L. (2010). Is the New Keynesian IS curve structural? ECB Working Paper 1236, European Central Bank, Frankfurt am Mein.

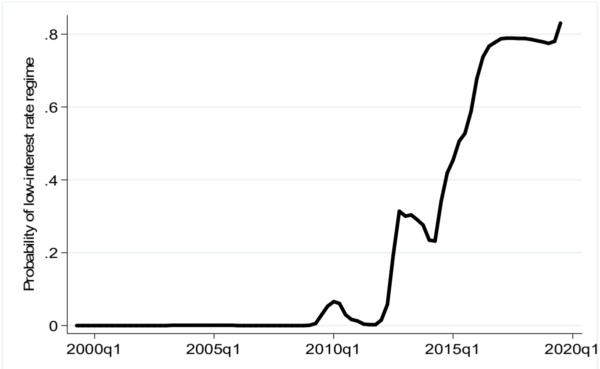
Tenreyro, S. and G. Thwaites (2016). Pushing on a string: US monetary policy is less powerful in recessions. *American Economic Journal: Macroeconomics*, 8(4), 43-74.

Van Arnum, B. and M. Naples (2013). Financialization and income inequality in the United States, 1967–2010. *American Journal of Economics and Sociology,* 72(5), 1158-1182.

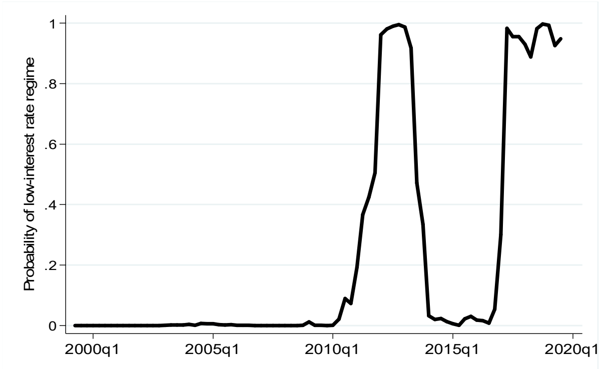
Appendix

Figure 1A. Probability of being in a low ($F_t = 1$) or normal interest regime ($F_t = 0$) based on smooth transition function F_t, proportion of the sample in low rate regime set to 20%, euro area

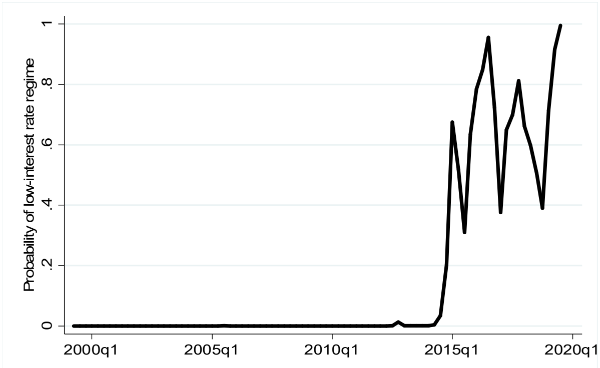
a) nominal short-term interest rate, *c*=0, *θ*=7



(b) real short-term interest rate, *c*=-1.2, *θ*=7



c) nominal long-term interest rate, *c*=1.3, *θ*=7



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

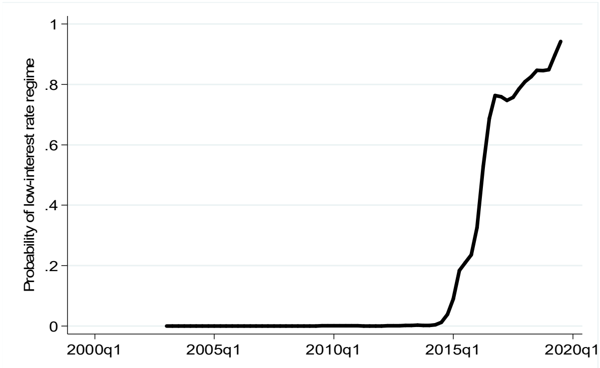
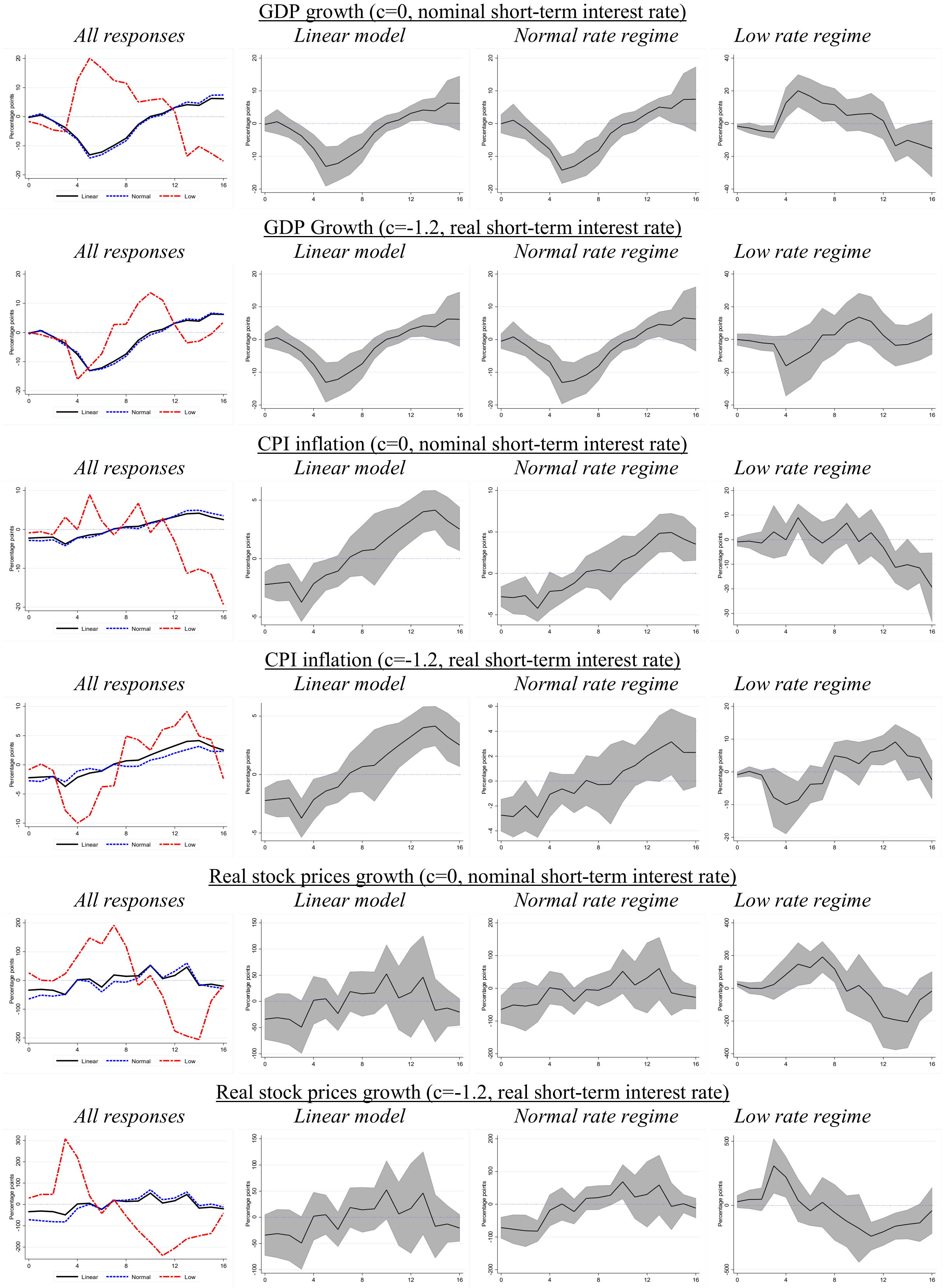


Table 1A. Joint Chi-squared test for the significance of differences between responses in a Normal and a Low interest rate regime, based on the baseline specification and the euro area data

	State variable	Chi(2)-statistic	P-value
Output gap	nominal short-term rate	42.63	0.00
Output gap	real short-term rate	59.91	0.00
Private consumption growth	nominal short-term rate	31.79	0.02
Private consumption growth	real short-term rate	59.67	0.00
Capital goods investment growth	nominal short-term rate	65.31	0.00
Capital goods investment growth	real short-term rate	106.75	0.00
Savings ratio growth	nominal short-term rate	77.26	0.00
Savings ratio growth	real short-term rate	114.26	0.00

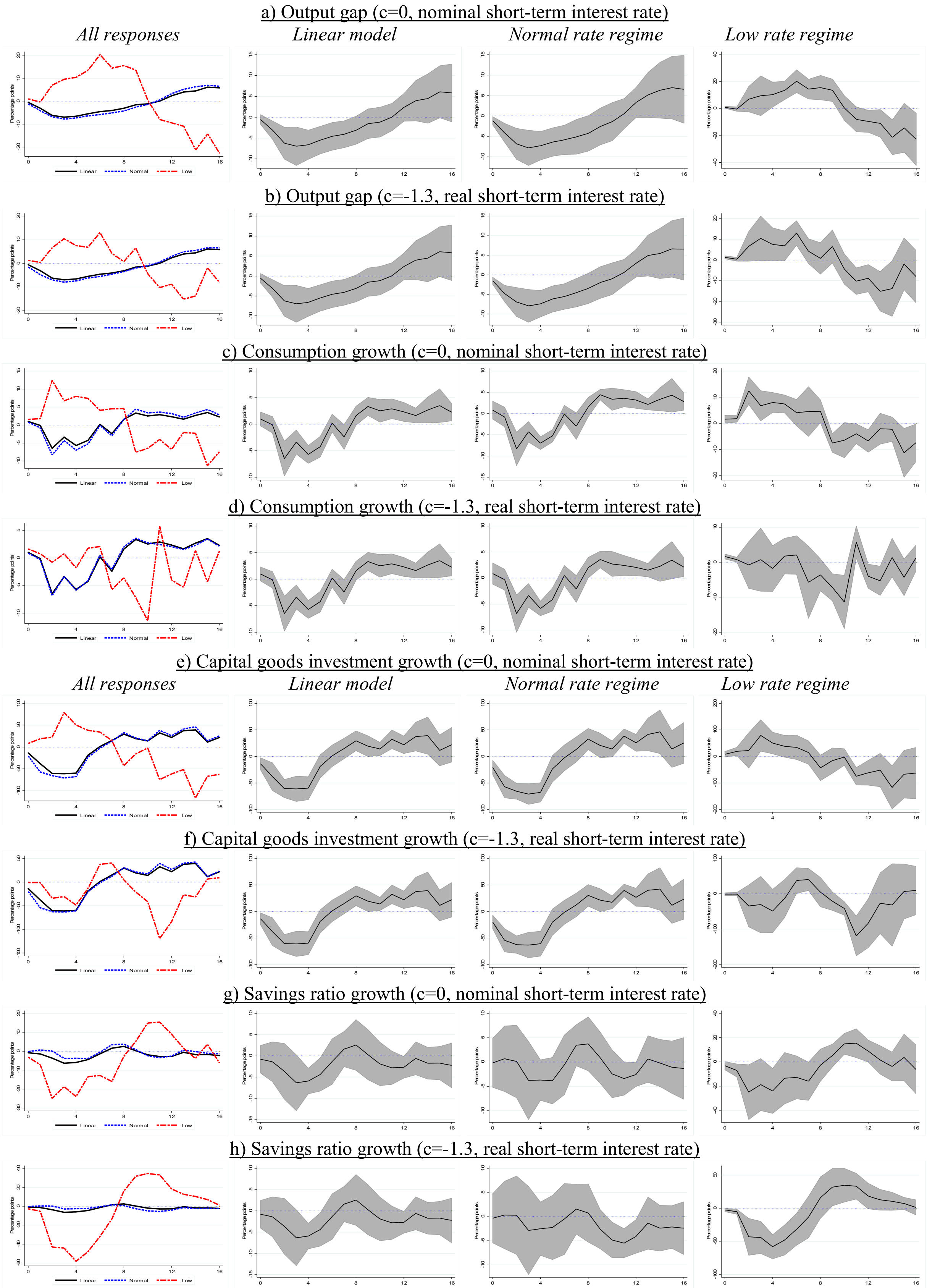
Notes: The table reports the joint Chi-squared test results for the significance of differences between the median impulse responses in a Normal and a Low interest rate regime, defined by a nominal (real) short-term interest rate as a state variable in a smooth transition function. P-value<0.01, <0.05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

Figure 2A. Impulse responses of y_{t+h} to 1 p.p. contractionary monetary policy shock, euro area



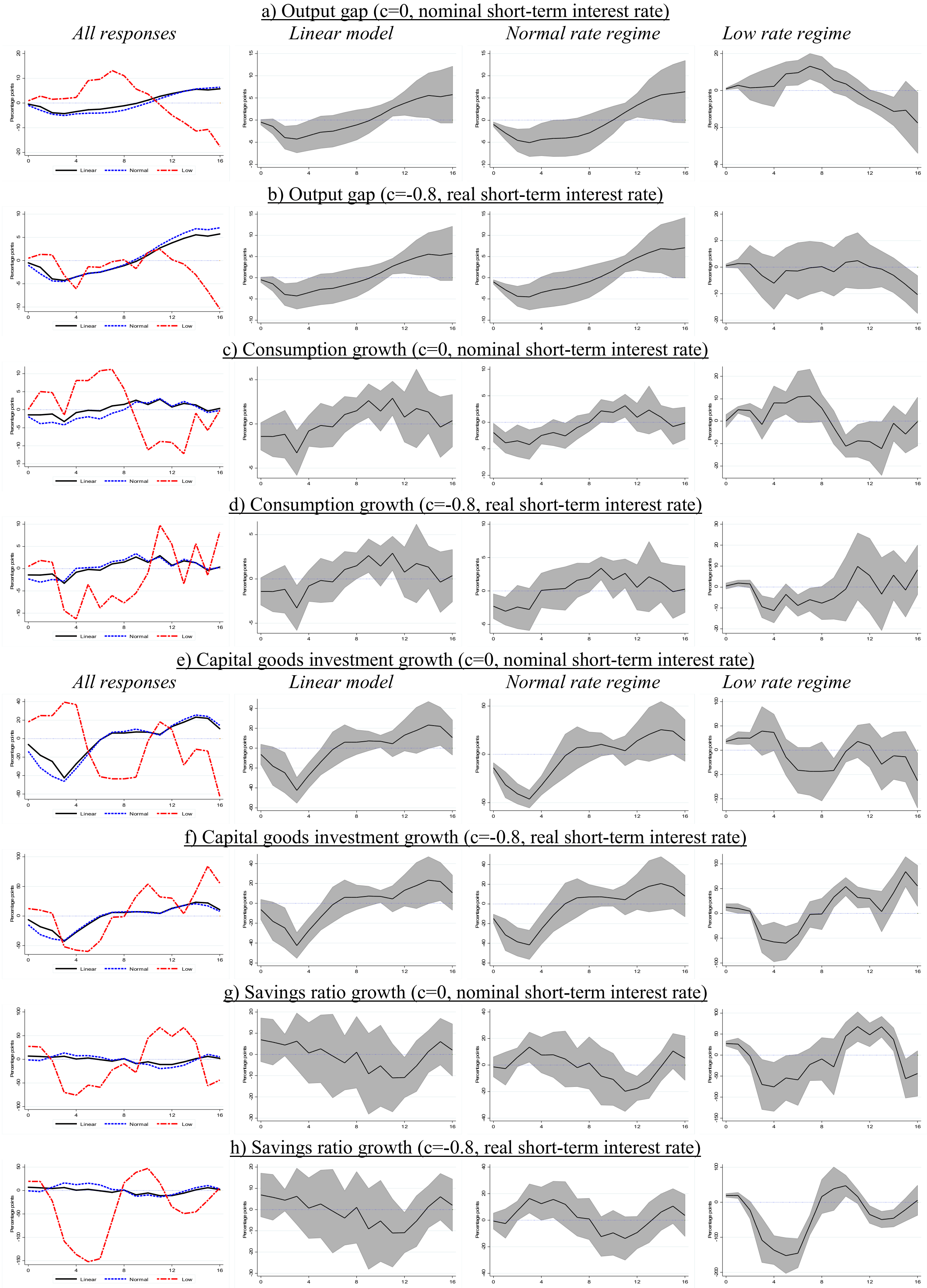
Notes: The figure plots impulse responses of real GDP growth, CPI inflation, and real stock prices growth to a 1 p.p. contractionary monetary policy shock. In the first column, the solid black line shows the response in a linear model, the blue dashed line - the response in a normal interest rate regime, and the red dash-dotted line - the response in a low rate regime. The second, third, and fourth columns show the responses in a linear model, normal, and low interest rate regime, respectively, with a 90% confidence interval around the responses (shaded area).

Figure 3A. Impulse responses of y_{t+h} to 1 p.p. contractionary monetary policy shock, Germany



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

Figure 4A. Impulse responses of y_{t+h} to 1 p.p. contractionary monetary policy shock, France

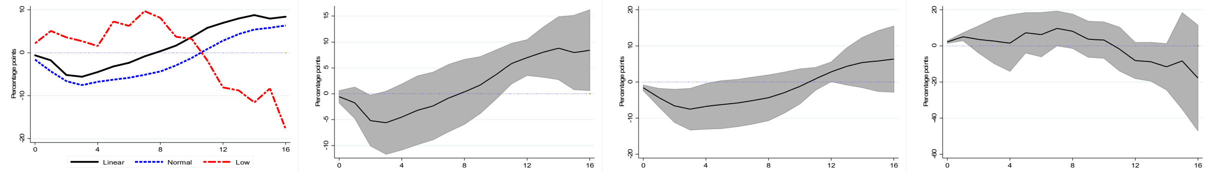


Notes: The figure plots impulse responses of the output gap, private consumption growth, capital goods investment growth, and savings ratio growth to 1 p.p. contractionary monetary policy shock. In the first column, the solid black line shows the response in a linear model, the blue dashed line - in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

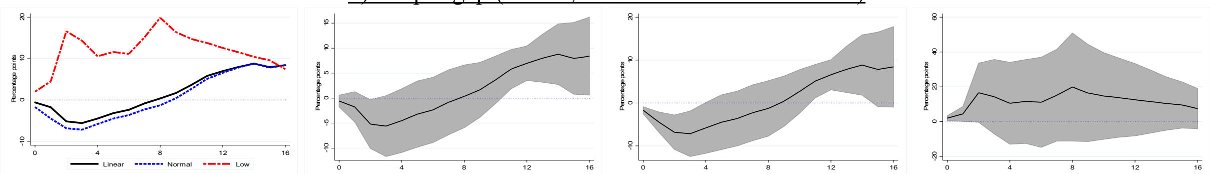
Figure 5A. Impulse responses of y_{t+h} to 1 p.p. contractionary monetary policy shock, Italy

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

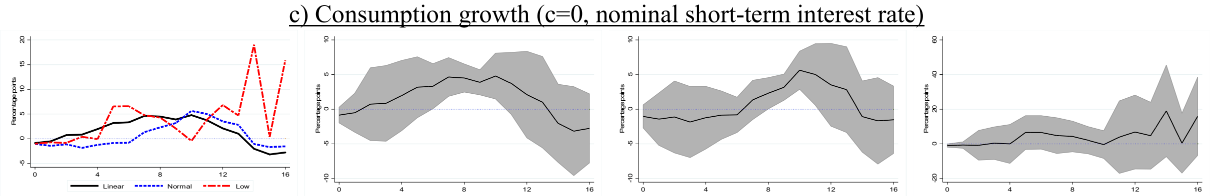
All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



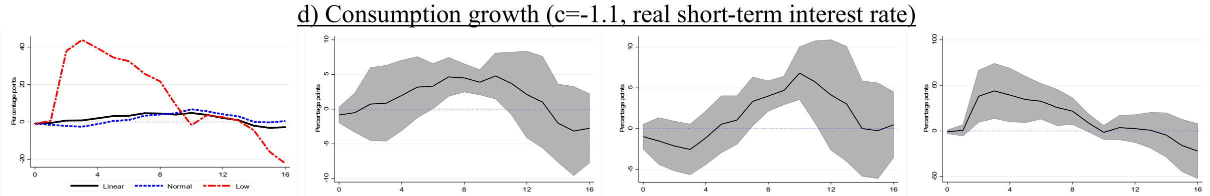
b) Output gap (c=-1.1, real short-term interest rate)



c) Consumption growth (c=0, nominal short-term interest rate)

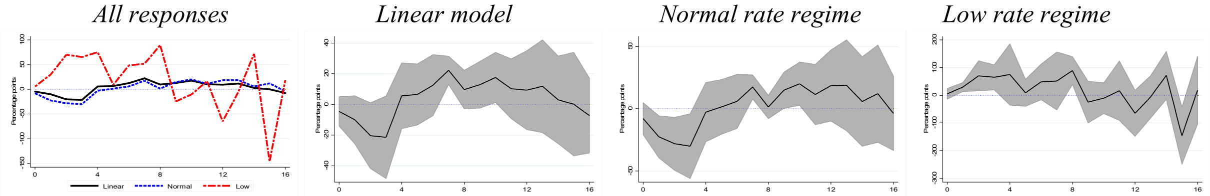


d) Consumption growth (c=-1.1, real short-term interest rate)

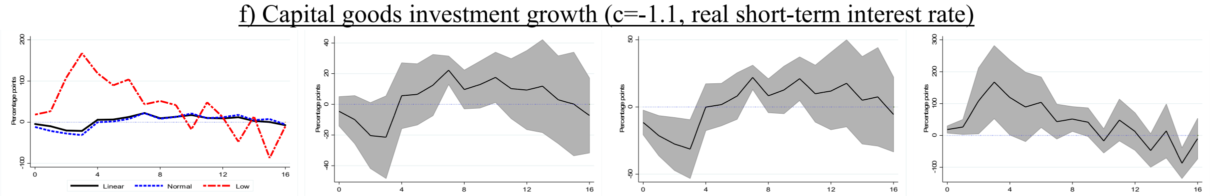


e) Capital goods investment growth (c=0, nominal short-term interest rate)

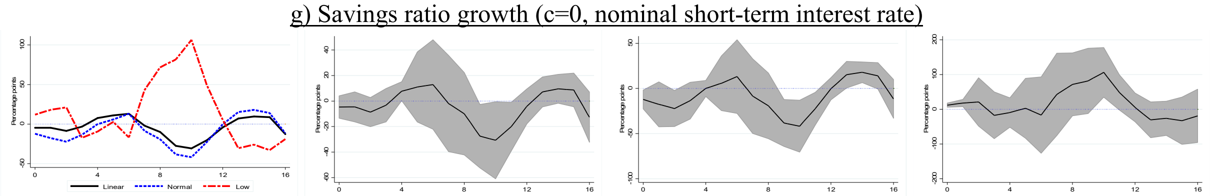
All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



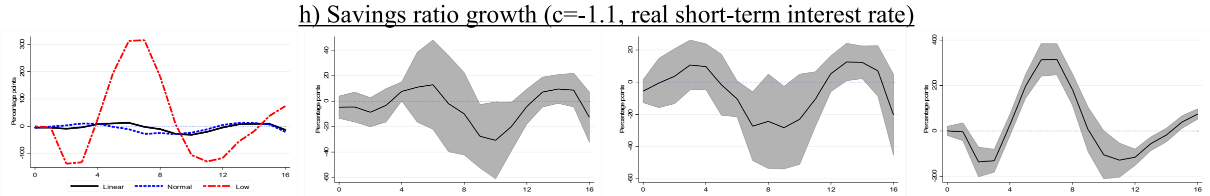
f) Capital goods investment growth (c=-1.1, real short-term interest rate)



g) Savings ratio growth (c=0, nominal short-term interest rate)

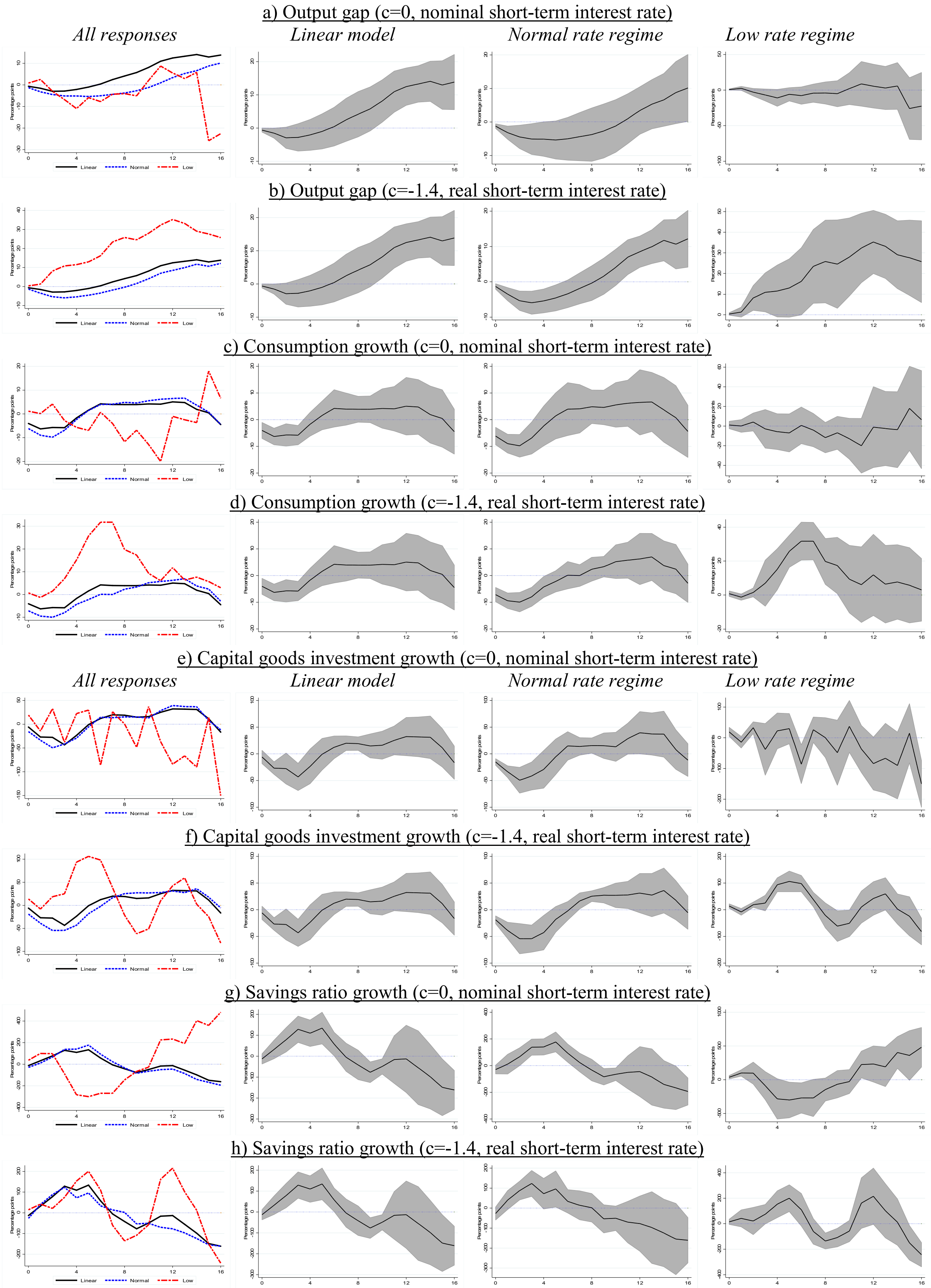


h) Savings ratio growth (c=-1.1, real short-term interest rate)



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

Figure 6A. Impulse responses of y_{t+h} to 1 p.p. contractionary monetary policy shock, Spain

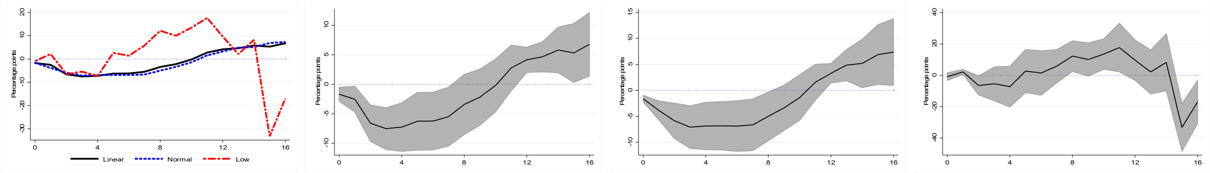


Notes: The figure plots impulse responses of the output gap, private consumption growth, capital goods investment growth, and savings ratio growth to 1 p.p. contractionary monetary policy shock. In the first column, the solid black line shows the response in a linear model, the blue dashed line - in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

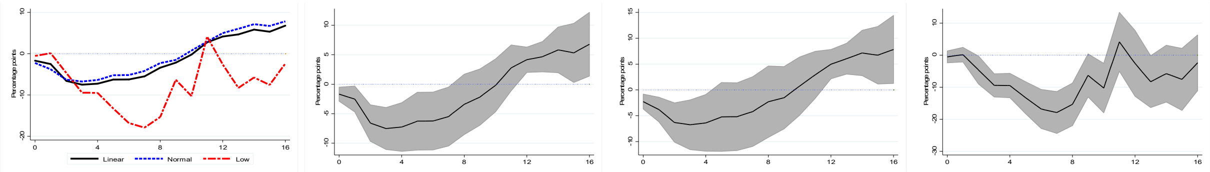
Figure 7A. Impulse responses of y_{t+h} to 1 p.p. contractionary monetary policy shock, Netherlands

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

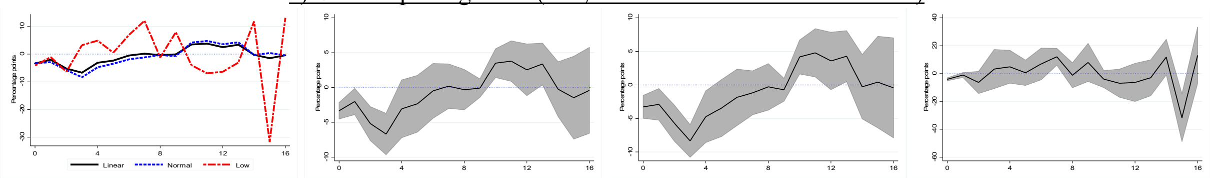
All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



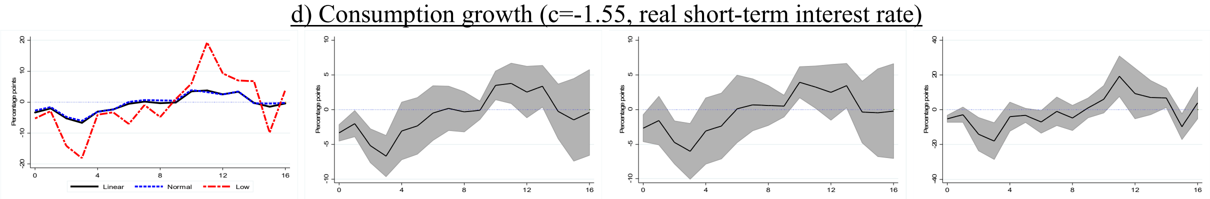
b) Output gap (c=-1.55, real short-term interest rate)



c) Consumption growth (c=0, nominal short-term interest rate)

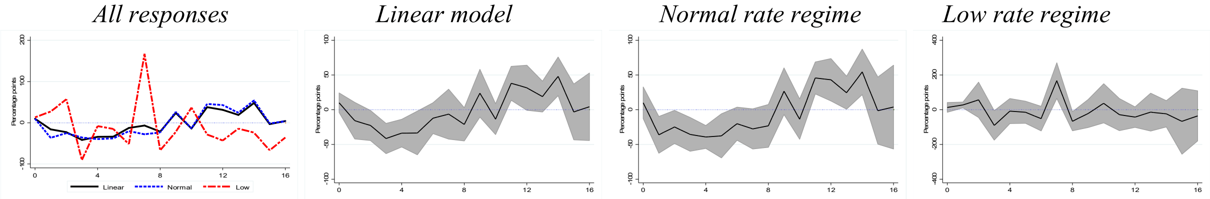


d) Consumption growth (c=-1.55, real short-term interest rate)

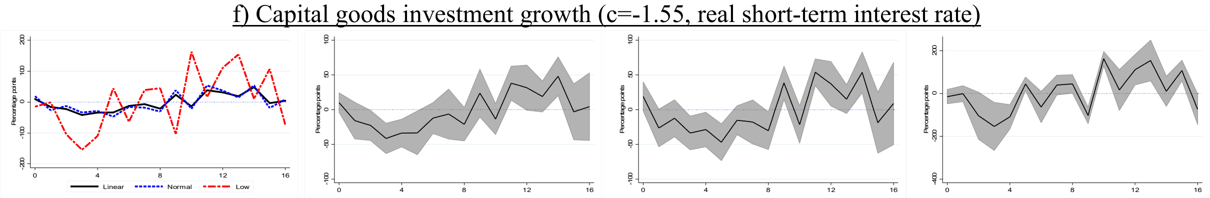


e) Capital goods investment growth (c=0, nominal short-term interest rate)

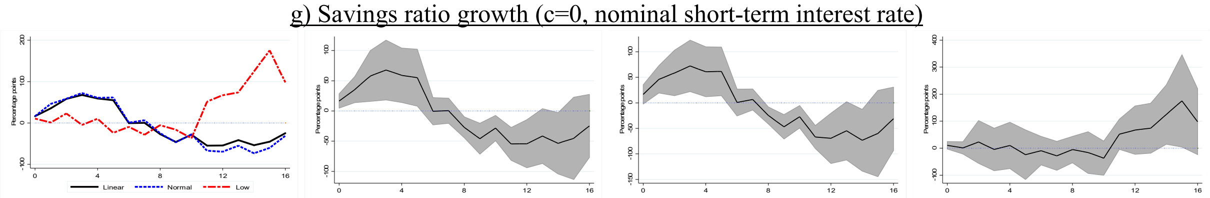
All responses | *Linear model* | *Normal rate regime* | *Low rate regime*



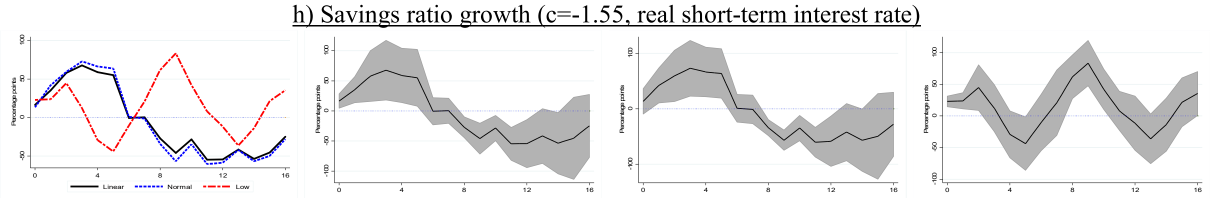
f) Capital goods investment growth (c=-1.55, real short-term interest rate)



g) Savings ratio growth (c=0, nominal short-term interest rate)



h) Savings ratio growth (c=-1.55, real short-term interest rate)



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

Table 2A. Impulse responses of the output gap for different threshold values *c* of a state variable (nominal short-term interest rate) in a smooth transition function, euro area data

Euro area	Baseline, *c=0%*		*c=0.25%*		*c=0.8%*		*c=1.5%*	
At horizon *h*=	Normal	Low *20% of sample*	Normal	Low *30% of sample*	Normal	Low *40% of sample*	Normal	Low *50% of sample*
0	-1.19 (0.36)	1.47 (0.58)	-1.14 (0.34)	0.81 (0.51)	-0.78 (0.34)	0.08 (0.46)	-0.65 (0.25)	0.07 (0.39)
4	-5.81 (3.00)	-1.07 (8.28)	-5.74 (2.97)	-1.32 (5.40)	-4.65 (2.93)	-3.91 (2.90)	-3.94 (2.69)	-0.14 (2.32)
8	-4.36 (3.24)	12.24 (5.12)	-4.23 (2.99)	7.53 (3.56)	-2.43 (2.41)	0.17 (2.82)	0.94 (2.06)	-0.29 (2.61)
12	2.66 (1.68)	2.78 (5.67)	2.53 (1.96)	6.59 (3.94)	3.16 (3.03)	4.39 (3.01)	7.07 (3.06)	0.91 (3.01)
16	7.32 (5.47)	-16.05 (14.14)	7.16 (5.64)	-4.03 (7.09)	6.76 (6.35)	1.29 (3.39)	9.17 (6.18)	-0.16 (2.63)

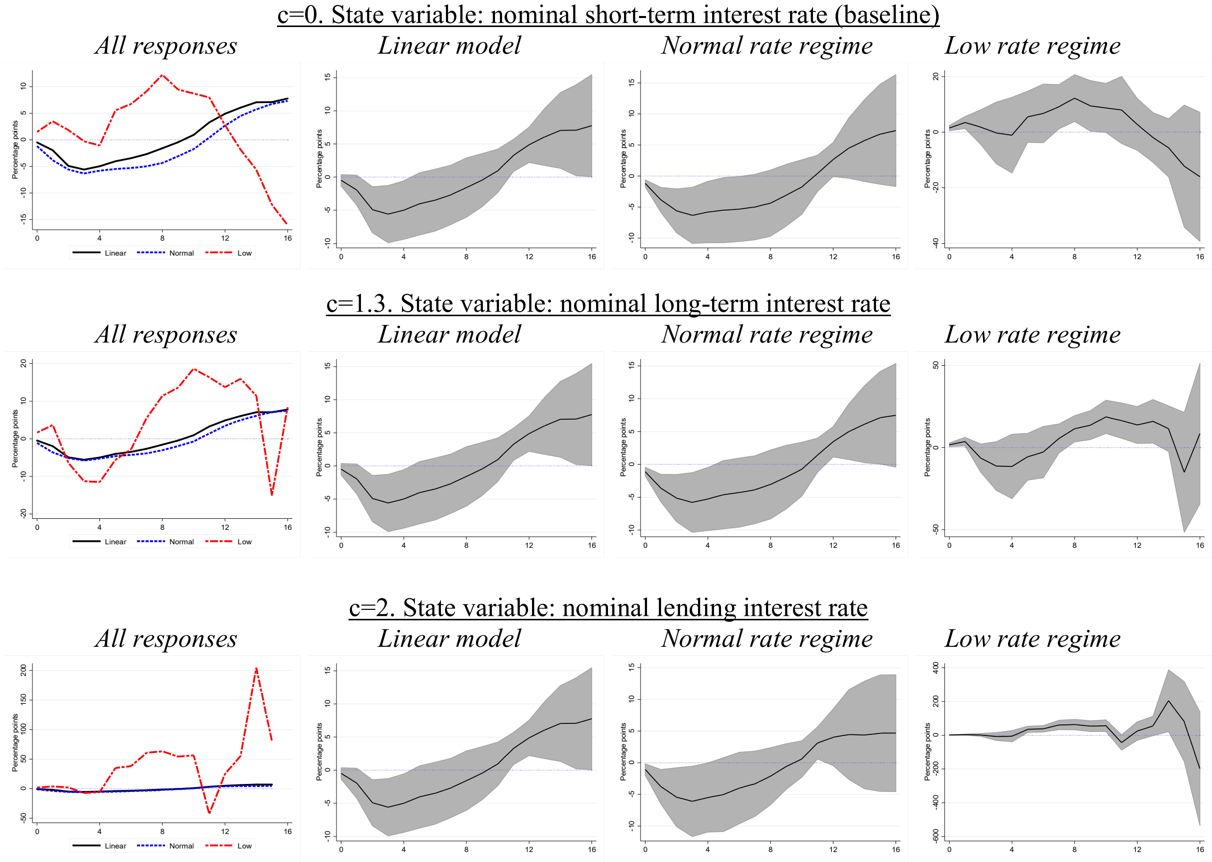
Notes: The table reports the median impulse responses (with Newey-West standard errors in parentheses) of the output gap in the euro area to a 1 p.p. contractionary monetary policy shock, in normal (Normal) and low interest rate regimes (Low).

Table 3A. Impulse responses of the output gap for different values of θ in a smooth transition function, *c=0* for a state variable (nominal short-term interest rate), euro area data

Euro area	Baseline, θ =7		θ =3		θ =10	
At horizon *h*=	Normal	Low	Normal	Low	Normal	Low
0	-1.19 (0.36)	1.47 (0.58)	-0.99 (0.28)	0.99 (0.82)	-1.19 (0.37)	1.41 (0.57)
4	-5.81 (3.00)	-1.07 (8.28)	-5.71 (2.69)	1.32 (6.57)	-5.68 (3.03)	-3.21 (7.63)
8	-4.36 (3.24)	12.24 (5.12)	-4.16 (2.59)	10.86 (5.60)	-4.09 (3.36)	9.64 (4.22)
12	2.66 (1.68)	2.78 (5.67)	2.32 (2.61)	9.48 (6.77)	2.97 (1.47)	-4.43 (4.90)
16	7.32 (5.47)	-16.05 (14.14)	6.77 (6.06)	-4.46 (12.23)	7.50 (5.24)	-26.18 (15.20)

Notes: The table reports the median impulse responses (with Newey-West standard errors in parentheses) of the output gap in the euro area to a 1 p.p. contractionary monetary policy shock, in normal (Normal) and low interest rate regimes (Low).

Figure 8A. Impulse responses of output gap to a 1 p.p. contractionary monetary policy shock for different state variables in a smooth transition function, euro area



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

Previous DNB Working Papers in 2020

No. 662 **Carin van der Cruijsen-Knoben, Jakob de Haan and Ria Roerink**, Financial knowledge and trust in financial institutions
No. 663 **Jon Frost,** Economic Forces Driving FinTech Adoption
No. 664 **Anna Samarina and Nikos Apokoritis,** Evolution of monetary policy frameworks in the post-crisis environment
No. 665 **Christian König-Kersting, Stefan T. Trautmann and Razvan Vlahu,** Bank instability: Interbank linkages and the role of disclosure
No. 666 **Claus Brand, Gavin Goy, Wolfgang Lemke,** Natural Rate Chimera and Bond Pricing Reality
No. 667 **Joost Bats,** Corporates' dependence on banks: The impact of ECB corporate sector Purchases
No. 668 **Marc van Kralingen, Diego Garlaschelli, Karolina Scholtus and Iman van Lelyveld,** Crowded trades, market clustering, and price instability
No. 669 **Mark Mink, Rodney Ramcharan and Iman van Lelyveld,** How Banks Respond to Distress: Shifting Risks in Europe's Banking Union
No. 670 **Jasmira Wiersma, Rob Alessie, Adriaan Kalwij, Annamaria Lusardi and Maarten van Rooij,** Skating on thin ice: New evidence on financial fragility
No. 671 **Michiel Bijlsma, Carin van der Cruijsen and Nicole Jonker,** Consumer propensity to adopt PSD2 services: trust for sale?
No. 672 **Duncan van Limbergen and Robert Vermeulen,** The importance of value chains for euro area trade: a time series perspective
No. 673 **Martijn Boermans en Bram van der Kroft,** Inflated credit ratings, regulatory arbitrage and capital requirements: Do investors strategically allocate bond portfolios?
No. 674 **Andras Lengyel and Massimo Giuliodori**, Demand Shocks for Public Debt in the Eurozone
No. 675 **Raymond Chaudron, Leo de Haan and Marco Hoeberichts,** Banks' net interest margins and interest rate risk: communicating vessels?
No. 676 **Martijn Boermans and John Burger**, Global and local currency effects on euro area investment in emerging market bonds
No. 677 **Patty Duijm and Ilke van Beveren**, Product diversification as a performance boosting strategy? Drivers and impact of diversification strategies in the property-liability insurance industry
No. 678 **Richard Heuver and Ron Berndsen,** Liquidity Coverage Ratio in a Payments Network: Uncovering Contagion Paths
No. 679 **Gabriele Galati, Jan Kakes and Richhild Moessner,** Effects of credit restrictions in the Netherlands and lessons for macroprudential policy
No. 680 **Frank van der Horst, Jelle Miedema, Joshua Snell and Jan Theeuwes,** Banknote verification relies on vision, feel and a single second
No. 681 **Leonard Sabetti and Ronald Heijmans,** Shallow or deep? Detecting anomalous flows in the Canadian Automated Clearing and Settlement System using an autoencoder
No. 682 **Shaun Byck and Ronald Heijmans,** How much liquidity would a liquidity-saving mechanism save if a liquidity-saving mechanism could save liquidity? A simulation approach for Canada's large-value payment system
No.683 **Neville Arjani and Ronald Heijmans,** Is there anybody out there? Detecting operational outages from LVTS transaction data

DeNederlandscheBank

EUROSYSTEEM

De Nederlandsche Bank N.V.
Postbus 98, 1000 AB Amsterdam
020 524 91 11
dnb.nl