The effect of forward guidance on Euro Area Economic activity in a DSGE model with interest rate expectations

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Abstract

We examine the effect of forward guidance in the Euro Area using two variants of a DSGE model estimated on macroeconomic data and data on market-based interest rate expectations. We find that the data strongly prefers the model variant where households have Preferences Over Safe Assets (POSA). The historical decomposition of the NOPOSA model suggests that the forward guidance announcement of the ECB post 2013Q2 increased the expansionary effect of monetary policy on the level of GDP by 4% and on year-on-year-inflation by 0.2 percentage points by the end of 2019Q4, while with POSA the effect is reduced to 1.9% and 0.1 percentage points, respectively.

Non-technical summary

The goal of this paper is to assess the effect of the forward guidance announcements of July 2013 and after on Euro Area Economic activity and inflation through the lens of two estimated DSGE models. For that purpose, we ad anticipated monetary policy shocks to the monetary policy rule and identify the associated stochastic processes by including market based measures of policy rate expectations (During the Euro Area period, EONIA swap rates (i.e. OIS rates)) as observables, on top of more standard macroeconomic data, following Campbell et al. (2019). The first model is a standard Smets and Wouters (2007) model. The second model differs from the first in that household have preferences over save assets (POSA), i.e. government bonds. As shown in Rannenberg (2019), POSA attenuate the effect of forward guidance both by making consumption less forward looking (so called "discounting" effect, and by creating a consumption wealth effect from government bonds).

*The opinions expressed here are those of the author and do not necessarily represent those of the National Bank of Belgium or the European System of Central Banks.

We obtain the following results. Firstly, while the empirical fit of the models is close in the absence of interest rate expectations from the dataset, the relative performance of the POSA model dramatically improves once this data is included, with the difference growing to 36 log points if the horizon of the interest rate expectations included in the dataset equals 12 quarters. Secondly, an expansionary anticipated monetary policy shocks may actually *increase* the nominal forward rate at the horizon it is expected hit, especially for long horizons, due to the stimulative effect of the anticipated monetary easing, as already noted by de Graeve et al. (2014). As expected, with POSA, the anticipated monetary policy shocks of the estimated model have a smaller effect on GDP at all horizons than without POSA, while the effect on the nominal forward interest rate at the horizon of the anticipated shock is consistently more negative.

Moreover, if we peg the interest rate below its steady state value for a fixed number of periods, we find that without POSA, GDP and inflation increase exponentially in the length of the peg, in line with the existing literature (see Campbell et al. (2019), Negro et al. (2012) and Carlstrom et al. (2015)). By contrast, in the model with POSA, the effect is not only substantially muted, but also becomes concave in the length of the peg, with the "wealth effect" playing a crucial role (see also Rannenberg (2019)). Hence the POSA model is not subject to the so called "Forward Guidance Puzzle".

Finally, regarding the effect of ECB forward guidance, the effects differ between the two models. The historical decomposition of the NOPOSA model shows that post 2013Q2, the combined contribution of the anticipated monetary policy shocks became gradually more expansionary (see Figure 7). By 2019Q4, this reversal had increased GDP by 4% relative to trend, and year-on-year inflation by 0.2 percentage points (see Figure 8). In the POSA model, the change in the combined contribution of the anticipated shocks to GDP and inflation amount to 1.9% and 0.1 percentage points over this period, respectively. In both models, the main driver of the low nominal policy and three year forward rate is a decline in aggregate demand rather than monetary policy. For the NOPOSA model, we find no perceptible effect of the more expansionary anticipated monetary policy shocks post 2013Q2 on the nominal three year forward rate, which is likely due to their strong stimulative effect in this model, and the associated ambiguous effect on the short term interest rate. By contrast, with POSA, the combined contribution of the anticipated monetary policy shocks on the 3 year forward rate becomes more negative post 2013Q2, by 0.8 percentage points.

1 Introduction

The goal of this paper is to assess the effect of the forward guidance announcements of July 2013 and after on Euro Area Economic activity and inflation through the lens of two estimated DSGE models. For that purpose, we ad anticipated monetary policy shocks to the monetary policy rule and identify the associated stochastic processes by including market based measures of policy rate expectations (EONIA swap rates (i.e. OIS rates), during the Euro Area period), on top of more standard macroeconomic data, following Campbell et al. (2019). The first model is a standard Smets and Wouters (2007) model. The second model differs from the first in that household have preferences over save assets (POSA), i.e. long- and short term government bonds. As shown in Rannenberg (2019), POSA attenuate the effect of forward guidance in the model for two reasons. POSA reduces the "net weight" the household attaches to future consumption, as with POSA the individual discount rate of the households exceeds the real interest rate, and creates a consumption wealth effect from government bonds.

We obtain the following results. Firstly, while the empirical fit of the models is close in the absence of interest rate expectations from the dataset, the relative performance of the POSA model dramatically improves once this data is included. Specifically, with 8-quarter-ahead-interest rate expectations, the POSA model outperforms the NOPOSA model by 24 log points. This difference grows to 36 log points if the horizon of the interest rate expectations included in the dataset rises to 12 quarters. Secondly, an expansionary anticipated monetary policy shocks may actually *increase* the nominal forward rate at the horizon it is expected hit, especially for long horizons, due to the stimulative effect of the anticipated monetary easing, as already noted by de Graeve et al. (2014). As expected, with POSA, the anticipated monetary policy shocks of the estimated model have a smaller effect on GDP at all horizons than without POSA, while the effect on the nominal forward interest rate at the horizon of the anticipated shock is consistently more negative. Fourthly, if we peg the interest rate below its steady state value for a fixed number of periods, we find that without POSA, GDP and inflation increase exponentially in the length of the peg, in line with the existing literature (see Campbell et al. (2019), Negro et al. (2012) and Carlstrom et al. (2015)). By contrast, in the model with POSA, the effect is not only substantially muted, but also becomes concave in the length of the peg, with the "wealth effect" playing a crucial role (the contribution of the wealth effect was also noted in Rannenberg (2019)). Hence the POSA model is not subject to the so called "Forward Guidance Puzzle".

Finally, regarding the effect of ECB forward guidance, the effects differ between the two models. The historical decomposition of the NOPOSA model shows that post 2013Q2, the combined contribution of the anticipated monetary policy shocks became gradually more expansionary. By 2019Q4, this change had increased GDP by 4% relative to trend and year-on-year inflation by 0.2 percentage points. In the POSA model, the change in the combined contribution of the anticipated shocks amount to 1.9% and 0.1 percentage points over this period, respectively. In both models, the main driver of the low nominal policy and three year forward rate is a decline in aggregate demand rather than monetary policy. For the NOPOSA model, we find no perceptible effect of the more expansionary anticipated monetary policy shocks post 2013Q2 on the nominal three year forward rate, due to the strong stimulative effect of anticipated expansionary monetary policy shocks in the model. By contrast, with POSA, the combined contribution of the anticipated monetary policy shocks on the 3 year forward rate becomes more negative post 2013Q2, by 0.8 percentage points.

Our estimation is an adaption of the estimation approach of Campbell et al. (2019) to the Euro Area context. Another recent contribution using expectations of interest rates and other variables as observables in the estimation of a Euro Area model is Christoffel et al. (2020), who draw on the Euro Area Survey of Professional Forecasters (SPF), as well as the Euro Area yield curve in some estimations. Our contribution differs from theirs in the following respects. Firstly, we use market interest rates to measure interest rate expectations instead of the SPF, implying that our estimation observe interest rate expectations starting in 1990Q1. For the post 1998 period, we rely on overnight index swap (OIS) rates, while during the pre-Euro Area period we construct our series from money market, Euro Market and government bond zero coupon yields (see B.3 for details). Secondly, we use interest expectations over a longer horizon, up to three years, similar to Campbell et al. (2019), who use expectations up to 10 quarters. The longer horizon may be relevant when assessing the contribution of ECB forward guidance. Thirdly, as in Campbell et al. (2019), for a given maximum horizon of interest rate expectations observed in an estimation (say 8 quarters), we observe the full yield curve (i.e. the average interest rate over the following quarter, the next 2 quarters from today, the next 3 quarters....,the next 8 quarters). Finally, we show that once interest rate expectations are included in the dataset, the data strongly prefers the model with POSA. By contrast, Christoffel et al. (2020) do not find evidence in favor of a related ad-hoc specification, which, like our POSA, does features “discounting” in the linearized consumption Euler equation but, unlike our POSA, does not feature a “wealth effect” of government bonds on consumption.

The remainder of the paper is structured as follows. Section 2 describes the model, Section 3 describes the estimation, the estimated parameters and how they are affected by the inclusion of interest rate expectations in the dataset, and the relative fit of the POSA and NOPOSA model(s). Section 4 discusses the IRFs and the effect of an interest rate peg. Section 6 examines the (change of the) contribution of the anticipated monetary policy shocks to economic activity and inflation post 2013Q2.

2 The model

Most features of the model are standard and closely follow Smets and Wouters (2007). However, there is a fiscal sector levying distortionary taxes on households and firms, with expenditures and tax rates responding to economic activity and debt via estimated fiscal rules. With POSA, households have preferences over government debt. When assuming POSA, we also assume preferences over the physical capital stock in order to leave the steady state capital stock and rental rate unaffected by POSA.

Smaller case letters now denote stationarized counterparts of trended variables, i.e. $x_t = \frac{X_t}{TFP_{t-1}}$, where TFP_{t-1} denotes the deterministic component of technology, determined as $TFP_t =$

γTFP_{t-1}. Unless otherwise mentioned, all variables denoted as $\varepsilon_{s,t}$ denote exogenous AR(1) processes with mean zero, where the subscript s indexes the respective shock, while $\eta_{s,t}$ denote i.i.d. normally distributed shock innovations.

2.1 Firms

There is a continuum of retailers indexed as f. The production function of retailer f is given by

$$Y_{f,t} = exp\left(\varepsilon_{a,t}\right)\left(TFP_{t-1}N_{f,t}\right)^{1-\alpha}\tilde{K}_{f,t}^{\alpha} - TFP_{t-1}\Phi \tag{1}$$

where $N_{f,t}$ denotes household labor hired by retailer f, respectively, while $\varepsilon_{a,t}$ and Φ denote a transitory technology shock and fixed costs of production, respectively, and $\tilde{K}_{f,t}$ denotes total capital services. Retailers produce a product variety from the goods basket consumed by households. Following Smets and Wouters (2007) , the basket is a Kimball (1995) aggregator. There are economy wide markets for all factors of production, implying that marginal costs are identical across firms. Furthermore, firms face nominal rigidities in the form of Calvo (1983) frictions, i.e. only a fraction $1-\omega_p$ is allowed to reoptimize its price, while, following Warne et al. (2008), the remaining fraction adjusts their prices according to the indexation scheme $P_t\left(f\right) = \Pi_{t-1}^{\iota_p}\Pi_{obj,t}^{(1-\iota_p)}$, with $0 \leq \iota_p \leq 1$, where $\Pi_{obj,t}$ denotes the potentially time-varying inflation target of the central bank. As shown in Smets and Wouters (2007) , up to first order these assumptions gives rise to the following New Keynesian Phillips Curve

$$\hat{\Pi}_t - \hat{\Pi}_{obj,t} = \frac{1}{1+\beta\iota_p}\left(\begin{array}{c} \beta E_t\left(\hat{\Pi}_{t+1} - \hat{\Pi}_{obj,t+1}\right) + \iota_p\left(\hat{\Pi}_{t-1} - \hat{\Pi}_{obj,t}\right) \\ +\iota_p\beta\left(\hat{\Pi}_{obj,t+1} - \hat{\Pi}_{obj,t}\right) + \frac{(1-\omega_p)(1-\omega_p\beta)}{\omega_p(\mu_p-1)\epsilon_p+1}\hat{mc}_t \end{array}\right) + \varepsilon_{p,t} \tag{2}$$

where μ_p, ϵ_p and $\varepsilon_{p,t}$ denotes the gross markup, the degree of curvature in the firms demand curve and the price markup shock, respectively. $\varepsilon_{p,t}$ follows an ARMA(1,1) process:

$$\varepsilon_{p,t} = \rho_p\varepsilon_{p,t-1} + \eta_{p,t} - \upsilon_p\eta_{p,t-1} \tag{3}$$

The retailer's FOCs with respect labor and physical capital can be aggregated as

$$\frac{W_t}{P_t} = mc_t\left(1-\alpha\right)\frac{Y_t + TFP_{t-1}\Phi}{N_t} \tag{4}$$

$$r_{K,t} = mc_t\alpha\frac{Y_t + TFP_{t-1}\Phi}{\tilde{K}_t} \tag{5}$$

2.2 Households

Household j derives utility from consumption $C_t(j)$, short term government bonds $\frac{B_{G,t}(j)}{P_t}$, long-term government bonds $\frac{B_{G,L,t}}{P_t}$, and holdings of physical capital $\bar{K}_t(j)$,and disutility from labor:

$$\sum_{i=0}^{\infty} \beta^i \left[\begin{array}{c} ln\left(C_{t+i}(j) - hC_{S,t+i-1}\right) + \frac{N_{t+i}^{1+\sigma_l}(j)}{1+\sigma_l} \\ +\frac{\chi_{b,t+i}}{1-\sigma_b}\left(\frac{B_{G,t+i}(j)}{P_{t+i}} + \frac{B_{G,L,t+i}(j)}{P_{t+i}}\right)^{1-\sigma_b} \\ +\frac{\chi_{K,t+i}}{1-\sigma_K}\bar{K}_{t+i}^{1-\sigma_K}(j) + \left(\frac{B_{G,t+i}(j)}{P_{t+i}} + \frac{B_{G,L,t+i}(j)}{P_{t+i}}\right)\chi_{\varepsilon_b,t+i}\varepsilon_{b,t+i} \end{array} \right] \tag{6}$$

We assume $\chi_{b,t} = \frac{\chi_b}{TFP_{t-1}^{1-\sigma_b}}$ and $\chi_{K,t} = \frac{\chi_K}{TFP_t^{1-\sigma_K}}$ in order to induce a balanced growth path. Furthermore, $\varepsilon_{b,t}$ denotes a liquidity demand shock as in Fisher (2015), which increases the desirability of holding safe assets, with mean zero, while $\chi_{\varepsilon_b,t} = \frac{\theta\xi}{TFP_{t-1}}$ merely normalizes the direct impact of $\varepsilon_{b,t}$ on the linearized household's FOCs with respect to bonds to equal the effect of a change in the short-term interest rate.

One motivation for utility from government bonds, or POSA, is liquidity preference. Krishnamurthy and Vissing-Jorgensen (2012) argue that liquidity preference may extend to assets with a positive yield if they have money-like qualities, and provide supporting evidence for the case of US government bonds. A motivation pertaining utility from all types of assets, including capital, are "Capitalist Spirit" type preferences over wealth, meaning that households derive utility from the prestige, power and security associated with wealth. Several authors have argued that such preferences are necessary to replicate rich household's saving behavior in US data, namely the positive marginal propensity to save out of permanent-income changes (see Dynan et al. (2004) and Kumhof et al. (2015)), and the level of wealth held by rich households relative to their disposable income (see Kumhof et al. (2015) for a survey). More recently, Kaplan and Violante (2018) have suggested using POSA as a simple shortcut to capture a feature of heterogeneous agent models, namely the idea that in the presence of uninsurable risk, the household sector values the existence of a safe and liquid asset due to its precautionary value.

The households faces four constraints. The first two are the budget constraint and capital accumulation equation:

$$\frac{B_{G,t}}{P_t}(j) + (1+\tau_{C,t}) C_t(j) + I_t(j) = \frac{R_{t-1}}{\Pi_t}\frac{B_{G,t-1}}{P_{t-1}}(j) + (1-\tau_{w,h,t}-\tau_{N,t})\frac{W_t(j)}{P_t}N(j)_t + Prof(j)_t \tag{7}$$

$$+ \left((1-\tau_{K,t})(r_{K,t}Z_t - a(Z_t)) + \tau_{K,t}\delta\right)\bar{K}_{t-1}(j) - T_t$$
$$- \frac{B_{G,L,n,t}(j)}{P_t} + \frac{(R_{G,L,t-1}(j) - 1 + \omega_{LTD})}{\Pi_t}\frac{B_{G,L,t-1}(j)}{P_{t-1}}$$

$$\bar{K}_t(j) = (1-\delta)\bar{K}_{t-1}(j) + \varepsilon_{I,t}\left(1 - S\left(\frac{I_t(j)}{I_{t-1}(j)}\right)\right) I_t(j) \tag{8}$$

where $\frac{B_{G,t}}{P_t}(j)$, R_{t-1}, $I_t(j)$, $W_t(j)$ and $Prof(j)_t$ denote short-term government bonds, investment, the nominal wage and the profits of monopolistically competitive firms and labor unions owned by households, respectively. $r_{K,t}$, Z_t, $a(Z_t)$, δ and $S\left(\frac{I_t(j)}{I_{t-1}(j)}\right)$ denote the capital rental, capacity utilization, convex costs of capacity utilization, the depreciation rate and the convex costs of adjusting investment, respectively. $\tau_{C,t}$, $\tau_{N,t}$ and T_t denote the consumption, labor and lump-sum tax, respectively, while $\tau_{w,h,t}$ denotes employees social security contributions.

Following Krause and Moyen (2016), we assume that long-term government bonds are re-payed in a stochastic fashion, with ω_{LTD} denoting the fraction of long-term bonds maturing each quarter. The final line of the budget constraints denotes the cash-flow associated with the households investment in long-term government bonds, where $B_{G,L,n,t}(j)$, $B_{G,L,t}(j)$, $R_{G,L,t}(j)$ and newly purchased long-term government bonds, total government bond holdings and the average interest rate on those government bonds. Hence $B_{G,L,t}(j)$ and $R_{G,L,t}(j)$ evolve according to

$$\frac{B_{G,L,t}(j)}{P_t} = (1-\omega_{LTD})\frac{\frac{B_{G,L,t-1}(j)}{P_{t-1}}}{\Pi_t} + \frac{B_{G,L,n,t}(j)}{P_t} \tag{9}$$

$$(R_{G,L,t}(j) - 1)\frac{B_{G,L,t}(j)}{P_t} = (1-\omega_{LTD})\frac{(R_{G,L,t-1}(j)-1)}{\Pi_t}\frac{B_{G,L,t-1}(j)}{P_{t-1}} + (R_{G,L,n,t}(j)-1)\frac{B_{G,L,n,t}(j)}{P_t} \tag{10}$$

which constitutes the third and fourth constraint faced by the household.

The full set of first order conditions is located in A.1. The first order condition with respect to short-term bonds is given by

$$\xi_t = \beta E_t\left\{\frac{\xi_{t+1}}{\gamma}\frac{R_t}{\Pi_{t+1}}\right\} + \chi_b\left(b_{G,t} + b_{G,L,t}\right)^{-\sigma_b} + \chi_\epsilon \varepsilon_{b,t} \tag{11}$$

where ξ_t denotes the marginal utility of consumption. The linearized first order condition illustrates the impact of POSA, and is given by

$$\hat{\xi}_t = \theta \left(E_t \hat{\xi}_{t+1} + \left(\hat{R}_t - E_t \Pi_{t+1} \right) + \varepsilon_{b,t} \right) - (1-\theta)\, \sigma_b \frac{y}{b_{G,L}} \hat{b}_{G,L,t}$$

where a hat on top of a variable denotes the percentage deviation of that variable from the non-stochastic steady state, with the exception of $\hat{b}_{G,L,t}$, which denotes the percentage point deviation of the government-debt-to-steady-state-GDP ratio, and we have used the fact that short term government bonds are in zero net supply. $\theta \equiv \frac{\beta}{\gamma} \frac{R}{\Pi}$, and represents the net weight that the household attaches to the $t+1$ marginal utility of consumption. Without POSA (i.e. $\chi_b = 0$), $\theta = 1$. As discussed in Rannenberg (2019), POSA attenuates the effect of forward guidance in two ways. Firstly, with $\theta < 1$, the (partial equilibrium) effect of a change in the future real interest rate $E_t \left\{ \hat{R}_{t+i} - E_t \Pi_{t+1+i} \right\}$ on consumption on declines in i. Secondly, if the policy succeeds at increasing economic activity and reducing the future real interest rate trajectory, $\hat{b}_{G,L,t+i}$ will be lower than in the absence of the policy, unless the government runs a balanced budget in each quarter. The lower trajectory for $\hat{b}_{G,L,t+i}$ feeds back negatively into consumption.

Following Smets and Wouters (2007), I assume that households supply their labor to labor unions owned by households. The unions differentiate the homogeneous household labor, and each supply one variety in a monopolistically competitive labor market with exactly the same characteristics as the goods market. Hence their wage setting is described by the standard New Keynesian wage Phillips Curve, and wages are subject to a wage mark-up shock analogous to the price markup shock:

$$\hat{w}_t = \frac{1}{1+\beta} \left(\begin{array}{c} \frac{(1-\omega_w)(1-\beta\omega_w)}{\omega_w(\mu_w-1)\epsilon_w+1} \left(\sigma_l \hat{N}_t - \hat{\lambda}_t + \frac{\hat{\tau}_{w,t}}{1-\tau_w} - \hat{w}_t \right) + \beta E_t \hat{w}_{t+1} \\ + \hat{w}_{t-1} + \beta E_t \hat{\Pi}_{t+1} - (1+\beta\iota_w)\, \hat{\Pi}_t + \iota_w \hat{\Pi}_{t-1} + (1-\iota_w) \left(\hat{\Pi}_{obj,t} - \beta E_t \hat{\Pi}_{obj,t+1} \right) \end{array} \right) + \varepsilon_{w,t} \tag{12}$$

2.3 Government and equilibrium

The monetary policy rule is given by

$$\begin{aligned} \left(\hat{R}_t - \hat{\Pi}_{obj,t} \right) = {} & (1-\rho_R) \left(\phi_\pi \left(\hat{\Pi}_t - \hat{\Pi}_{obj,t} \right) + \phi_y YGAP_t \right) + \phi_{\Delta \mathrm{y}} \left(YGAP_t - YGAP_{t-1} \right) & (13) \\ & + \rho_R \left(\hat{R}_{t-1} - \hat{\Pi}_{obj,t-1} \right) + \varepsilon^0_{R,t} + \sum_{i=1}^{H} \varepsilon^i_{R,t-i} \end{aligned}$$

$$\varepsilon^i_{R,t} = \rho^i_R \varepsilon^i_{R,t-1} + \eta^i_{R,t} \text{ for } i = 0, 1, ..., H \tag{14}$$

$$\hat{\Pi}_{obj,t} - 0.999 \hat{\Pi}_{obj,t-1} = \rho_{obj} \left(\hat{\Pi}_{obj,t-1} - 0.999 \hat{\Pi}_{obj,t-2} \right) + \eta_{\pi_{obj},t} \tag{15}$$

with $YGAP_t = (\hat{y}_t - \hat{y}_t^*)$ and $\hat{y}_t^*$ denoting flexible price output. This specification follows Smets and Wouters (2007), except for the $\sum_{i=1}^{H} \varepsilon_{R,t-i}^{i}$ and $\hat{\Pi}_{obj,t}$ terms. $\sum_{i=1}^{H} \varepsilon_{R,t-i}^{i}$ represents anticipated monetary policy shocks, which are active only in those estimations including forward rates as measures of expected future policy rates in the dataset. Following Rannenberg (2020), we allow for autocorrelation of the anticipated monetary policy shock, as it dramatically improves the empirical fit of the estimated models. Finally, we specify the process for the time-varying inflation target $\hat{\Pi}_{obj,t}$ such that it captures exclusively low frequency movements of inflation, similar to Cogley et al. (2010) and Del Negro et al. (2015).

We assume that short term government bonds are in zero net supply. The government budget constraint is therefore given by

$$\frac{B_{G,L,t}}{P_t} = \frac{R_{G,L,t-1}}{\Pi_t}\frac{B_{G,L,t-1}}{P_{t-1}} + G_t - \left(T_t + \left(\tau_{N,t} + \tau_{w,h,t} + \tau_{w,f,t}\right) w_t L_t + \tau_{C,t} C_t + \tau_K Prof_t\right) \tag{16}$$

$$Prof_t = Y_t - \left(1 + \tau_{w,f,t}\right)\frac{W_t}{P_t} L_t - \left(\delta + a\left(U_t\right)\right)\bar{K}_{t-1} - \Phi TFP_{t-1} \tag{17}$$

where G_t and $Prof_t$ denote government expenditure and total real profits. The various taxes are either determined as

$$\hat{u}_{tax,t} = \rho_{tax}\hat{u}_{tax,t-1} + \left(1 - \rho_{tax}\right)\phi_{b,tax}\left(\hat{b}_{G,L,t-1}\left(\frac{y}{b_{G,L}}\right)\right) + \left(1 - \phi_{tax}\right)\eta_{tax,t} + \phi_{tax}\eta_{tax,t-1} \tag{18}$$

$$\hat{tax}_t = \phi_{y,tax}\hat{y}_t + \hat{u}_{tax,t}$$

with $\phi_{b,tax} > 0$, or held constant, depending on the tax data used in the estimation. The hat in $\hat{tax}_t$ refers to a percentage *point* deviation from the respective steady-state value. $\eta_{g,t}$ and $\eta_{tax,t}$ denote i.i.d. normally distributed random variables. In the baseline estimation, we have $tax = \{\tau\}$,where $\tau_t = \frac{\frac{T_t}{TFP_{t-1}}}{y}$. [1]

These fiscal rules embed the following features. Following Leeper et al. (2010a,b) they allow for a response of all fiscal instruments to contemporaneous output in order to capture "automatic stabilizer" effects. Romer and Romer (2010) argue that accounting for the effect of economic activity on fiscal policy is important for correctly identifying discretionary fiscal policy changes. Furthermore, the rules allow exogenous fiscal policy changes to be anticipated one quarter in advance (e.g. the $\left(1 - \phi_{tax}\right)\eta_{tax,t} + \phi_g\eta_{tax,t-1}$ term), a feature whose importance is stressed in Susan Yang (2005) and Leeper et al. (2013), and used in the estimated model of Coenen et al. (2013). Finally, I

[1] The multiple $\frac{y}{b_{G,L}}$ was simply added to facilitate comparison of the coefficient $\left(1 - \rho_g\right)\phi_{b,tax}$ to its counterpart in fiscal rules of other studies, which typically express the debt deviation from steady state as a percentage of its own steady-state value, whereas here $\hat{b}_{G,L,t-1}$represents the deviation as a percentage of steady-state GDP.

allow the fiscal instruments to respond to the level of government debt in a debt-stabilizing fashion.

The resource constraint is given by

$$Y_t = C_t + I_t + G_t + EX_t \tag{19}$$

where EX_t denotes "exogenous spending" not accounted for elsewhere in the model, and in practice captures net exports and inventories. In the model it is driven by an exogenous spending shock $\varepsilon_{EX,t}$, which is expressed in units of trend GDP, and follows the process

$$\varepsilon_{EX,t} = \rho_{EX}\varepsilon_{EX,t-1} + \eta_{EX,t} + \rho_{a,EX}\eta_{a,t} \tag{20}$$

3 Estimation

3.1 Data and observation equations

We estimate the model on Euro Area data over the 1980Q1-2019Q4 period. In all estimated model variants, I use the seven data series used by Smets and Wouters (2007) , i.e. the growth rates of real GDP (GDP_t), consumption ($CONS_t$), private fixed investment ($INVE_t$), the real wage ($WREAL_t$) and the GDP deflator (YED_t), as well as the short term interest rate STI_t, and a measure of employment ($\widehat{EMPL}_t$) in levels. Furthermore, we include the government deficit-to-GDP ratio DY_t in the estimation. We construct the macroeconomic and fiscal variables using the Area Wide Model database of Fagan et al. (2005) and the Euro Area fiscal database of Paredes et al. (2014) . Long-run inflation expectations are defined as the average inflation rate during the 6th-10th year from today. Further details on data construction are located in B. Hence the measurement equations are given by

$$\begin{bmatrix} \Delta ln\left(GDP_t\right)*100 \\ \Delta ln\left(CONS_t\right)*100 \\ \Delta ln\left(INVE_t\right)*100 \\ \Delta ln\left(WREAL_t\right)*100 \\ \widehat{EMPL}_t \\ \Delta ln\left(YED_t\right)*100 \\ STI_t \\ CPI510_t \\ DY_t \end{bmatrix} = \begin{bmatrix} 100\left(\gamma-1\right) \\ 100\left(\gamma-1\right) \\ 100\left(\gamma-1\right) \\ 100\left(\gamma-1\right) \\ empl \\ 100\left(\Pi-1\right) \\ 400\left(R-1\right) \\ 0.16+400\left(\Pi-1\right) \\ 100\frac{b_{G,L}}{y}\left(1-\frac{1}{\Pi\gamma}\right) \end{bmatrix} + \begin{bmatrix} \hat{y}_t-\hat{y}_{t-1} \\ \hat{c}_t-\hat{c}_{t-1} \\ \hat{i}_t-\hat{i}_{t-1} \\ \hat{w}_t-\hat{w}_{t-1} \\ e\hat{mpl}_t \\ \hat{\Pi}_t \\ 4\hat{R}_t \\ 4\left(\frac{\sum_{i=21}^{40}E_t\hat{\Pi}_{t+i}}{20}\right) \\ \hat{b}_{G,L,t}-\frac{\hat{b}_{G,L,t}}{\Pi\gamma} \\ +\frac{b_{G,L}}{y}\left(\left(\gamma\Pi-1\right)\hat{y}_t-\hat{\Pi}_t\right) \end{bmatrix}$$

where $\bar{n}$ denotes the model's steady state level of log hour and $100\left(\frac{b_{G,L}}{y}\right)\left(1-\frac{1}{\Pi\gamma}\right)$ represents the model's steady state deficit ratio. In the $CPI510_t$ measurement equation, 0.16 represents the average difference between the annualized growth rate of the CPI and the GDP deflator over the period where data is available for $CPI510_t$, i.e. 1992Q2-2019Q4. Since employment in the data is measured in heads, the Smets and Wouters (2003) bridge equation links $\hat{empl}_t$ to the deviation of hours from its steady state $\hat{n}_t$:

$$\hat{empl}_t - \hat{empl}_{t-1} = \beta\left(E_t\hat{empl}_{t+1} - \hat{empl}_t\right) + \frac{(1-\omega_N)(1-\beta\omega_N)}{\omega_N}\left(\hat{n}_t - \hat{empl}_t\right) \tag{21}$$

Furthermore, in some estimations we use measures of the average expected short-term interest rate over horizon i $STIEX_{i,t}$, following Del Negro et al. (2017) and Campbell et al. (2019). This gives rise to an additional H measurement equations:

$$STIEX_{i,t} = 400\,(R-1) + 4\frac{E_t\sum_{j=1}^{i}\hat{R}_{t+j}}{i} \text{ for } i = 1, 2, ..., H \tag{22}$$

Below I report estimation results for values of $H = 8$ and $H = 12$.

We make sure that our choice of data for $STIEX_{i,t}$ and STI_t are as mutually consistent as possible. For example, during the post-1998 period, STI_t is the quarter t average of the Euro Overnight Index Average (EONIA), while $STIEX_{i,t}$ are EONIA Overnight Index Swap (OIS) rates from the end of quarter t. Using the end-of-quarter value implies that can indeed be interpreted as $STIEX_{i,t}$ an expectation of the average EONIA over period $t+1$ to $t+i$, and thus the average value of STI_t. Campbell et al. (2019) adopt the same timing convention.[2] During 1994Q1-1998Q4 period, STI_t equals the one-quarter Euribor yield from the beginning-of-quarter t.[3] For $i = 1-4$, $STIEX_{i,t}$ equal the end-of-quarter t values of one to four quarter Euribor yield. For $i = 5-12$, we construct $STIEX_{i,t}$ from a GDP weighted average of government bond Zero Coupon Yields of the most important economies of the later Euro Area, adjusted for the difference between $STIEX_{4,t}$ and the one year government bond yield (see B.3. for further details).[4]

The main reason for including measures of interest rate expectations in the dataset is to identify the anticipated monetary policy shocks. Furthermore, as mentioned above, the attenuation of

[2] Using the end-of-period t values of the OIS rates as measures of $STIEX_{i,t}$ relies on the assumption that when making their period-t decisions, agents know all data occurring during quarter t. Note that this assumption is already implicit in the observation equations all the other variables. For instance, we assume that agents know the total value of quarter t GDP when making their decisions, regardless of how production is distributed across the three months of the quarter.

[3] Note that the using the beginning-of-quarter t value of the three-month Euribor is in fact consistent with using the quarter t average of the EONIA. The reason is the Euribor's three-month maturity, which implies that it is the beginning-of-quarter t yield which applies to funds deposited from the beginning of quarter t until the beginning of quarter $t+1$. By contrast, the EONIA is an overnight rate, and thus it is the quarter t average yield which applies to funds deposited from the beginning of quarter t until the beginning of quarter $t+1$.

[4] Dynare treats the missing values of the the interest rate expectations and long-run inflation expectations as unobserved states and uses the Kalman filter to infer their value (see the Dynare 4.5.7 manual).

consumption smoothing and the "wealth effect" associated with POSA strongly attenuate the effect of changes in expected future interest rates, or forward guidance, as discussed in more detail in Rannenberg (2019). Hence one way to examine whether the data favors the mechanism POSA adds to the model is to include a measure of the expectation of the future path of the short-term interest rate in the estimation. Furthermore, incorporating such measures in the dataset implies that the estimation respects the Effective Lower Bound (ELB) on the short-term interest rate by forcing not merely contemporaneous values of the short term interest rate to exceed the ELB, but also expected future ones, as pointed out by Campbell et al. (2019). The motivation for including the government deficit deficit is that via this avenue, the estimation implicitly takes into account the dynamics of government debt, which would be expected, inter alia, to discipline the estimation of the safe asset curvature parameter σ_b, since for a given debt trajectory, different values of σ_b imply a different trajectory of the "wealth effect" of government debt on consumption. Gadatsch et al. (2016) also used the government deficit as an observable.

In all estimations, the number of shocks equals the number of observable variables. In the absence of interest rate expectations from the dataset, the model has 9 exogenous driving processes, namely $\varepsilon_{a,t}$, $\varepsilon_{risk,t}$,$\varepsilon_{I,t}$, $\varepsilon^0_{R,t}$, $\varepsilon_{p,t}$, $\varepsilon_{w,t}$,$\varepsilon_{x,t}$, $\eta_{\tau,t}$ and $\hat{\Pi}_{obj,t}$. Estimations including forward rates in the dataset feature H additional observables and exactly H additional exogenous driving processes, namely $\varepsilon^1_{R,t}, \varepsilon^2_{R,t}, ...,\varepsilon^H_{R,t}$, as in Del Negro et al. (2017). In that respect our approach differs somewhat from Campbell et al. (2019), who place a more complex stochastic structure on the anticipated monetary policy shocks. Their structure results in a total number of exogenous drivers related to the anticipated monetary policy shocks which exceeds the total number of forward rates included in their estimation.

3.2 Calibrated parameters and priors

I calibrate a number of parameters in advance of the estimation, displayed in Table 1. The depreciation rate, the wage and price markup and the curvature of the Kimball aggregators in the goods and labor market are set to standard values (see Lindé et al. (2016)). Since the inverse Frisch elasticity of labor supply σ_l is inherently difficult to identify, I calibrate it to 2, in line with available estimates in the literature. Following Smets and Wouters (2007), to pin down the fixed cost parameter, I assume that retailers earn zero profits in the steady state, implying that $\mu_p = \frac{\Phi+y}{y}$, with μ_p estimated. I set the steady-state distortionary tax rate τ_C to its sample average. Following Coenen et al. (2013), I construct this tax rate as an implicit rate from the Euro Area Fiscal database of Paredes et al. (2014) and the Area Wide Model database of Fagan et al. (2005). I assume $\tau_K = \tau_N$, and set τ_N to the sample average ratio of total direct taxes (excluding social security contributions) to GDP.[5]

[5]The Euro Area fiscal database does not distinguish between taxes on capital and labor incomeParedes et al. (2014).

Given these choices and the parameters to be estimated, I restrict 12 parameters in order to meet 12 steady-state targets, which unless otherwise mentioned I calculate as averages over the sample period. These parameters are reported in Table 1 (marked with a *) if their value implied by the empirical targets does not depend on the estimated parameters, and could thus be set in advance of the estimation. The 12 targets, listed in Table 2, are the average GDP deflator inflation rate (which directly pins down Π), the average growth rate of real GDP per capita (which directly pins down γ), the average real short term interest rate, the average private investment share, the average government expenditure share, average maturity of outstanding government debt, the average share of "exogenous" (i.e. non-modeled) expenditure in GDP (i.e. the sum of inventory investment and net exports), the average government-debt-to-GDP-ratio, the shares of employee and employer social security contributions in GDP and the share of labor tax revenue in GDP.[6]

To calibrate the bond utility weight χ_b, I follow Rannenberg (2019) in assuming an empirical target for the discounting wedge θ $(= \frac{\beta}{\gamma}\frac{R}{\Pi})$. This target pins down the steady-state marginal utility of save assets via $1-\theta = \frac{\chi_b (b_{G,L})^{-\sigma_b}}{\xi}$ (from equation (11)), which, given the estimate of the curvature parameter σ_b, pins down the safe asset utility weight χ_b. For instance, the case without POSA corresponds to $\theta = 1 \Longleftrightarrow \chi_b = 0$. Given the aforementioned target for $\frac{R}{\Pi}$ and γ, we can pin down β as $\beta = \frac{\gamma\theta}{R/\Pi}$. To pin down the capital utility weights χ_K, I assume that in the POSA model, the steady state return on capital $(r_K - \delta)(1-\tau_K)+1$ is the same as for $\theta = 1$.

With POSA, we set the discounting wedge $\theta = 0.96$ as in Rannenberg (2019), who obtains evidence on θ by drawing on 34 empirical estimates of the (time-varying) nominal individual discount rate which the household applies to future nominal income streams, $DIS_t = \frac{1}{E_t\left\{\frac{\beta\Lambda_{t+1}}{\Lambda_t\Pi_{t+1}}\right\}}$.[7]

Turning to the prior distributions, we assume that the safe asset curvature σ_b follows a normal prior distribution with mean 0.4 and standard deviation 0.05, similar to Rannenberg (2020). For the capital curvature parameter σ_K, where there is less guidance from the literature, we assume a very diffuse normal prior with a mean of one. Regarding the debt feedback coefficient in the fiscal rules, our priors have the same form but are wider than those of Zubairy (2014), Leeper et al. (2010a), Leeper et al. (2010b) and Leeper et al. (2017).[8] Regarding the output feedback coefficients, I assume a zero feedback for the consumption tax ($\phi_{y,\tau_C} = 0$), and fairly diffuse normal prior and a zero mean for lump-sum and labor tax feedback coefficients $\phi_{y,\tau}$ and ϕ_{y,τ_w}. The prior distributions of the parameters unrelated to the fiscal rule are taken from Smets and Wouters (2007) and Lindé

[6]The reason for calibrating the steady-state social security contribution rates $\tau_{w,h}$ and $\tau_{w,f}$ based on the revenue-to-GDP ratios, rather than calculating an implicit tax rate, is that the steady-state labor share exceeds the sample average, because following Smets and Wouters (2007), I set retailers fixed costs such that their steady-state profits equal zero. Matching the labor-tax-to-GDP should improve the models ability to capture the feedback from an increase in the wage bill to the deficit.

[7]Given estimates of DIS_t, Rannenberg (2019) exploits the fact that for sufficiently small weights on safe assets in the utility function (i.e. θ smaller than but close to one), $\theta_t = \frac{R_t}{DIS_t}$ is approximately constant across time in the model.

[8]Note that $\hat{\tau}_t = d\tau_t$, while in the aforementioned papers the fiscal rule applies to $\frac{d\tau_t}{\tau}$.

Table 1: Calibration

Parameter	Parameter name	Model	
		NOPOSA	POSA
β	Household discount factor	0.9979*	0.9580*
σ_l	Inverse Frisch elasticity of labor supply	2.0	
γ	Quarterly gross growth rate of deterministic technology	1.0032*	
Π	Quarterly gross inflation rate	1.0079*	
δ	Depreciation rate	0.025	
μ_w	Wage markup	1.5	
ϵ_p	Kimball goods market curvature	10	
ϵ_w	Kimball labor market curvature	10	
τ_C	Consumption tax rate	22.3%	
τ_N	Labor tax rate	11.8*	
$\tau_{w,f}$	Employer social security contribution rate	11.5%*	
$\tau_{w,h}$	Employee social security contribution rate	10.9%*	
τ_K	Capital tax rate	11.8%	
$\frac{B_{G,L}}{4PY}$	Fiscal rule, target debt-to-annual GDP ratio	66.2%*	
$\frac{G}{Y}$	Fiscal rule, steady-state government expenditure share	23.5%*	
$\frac{ex}{y}$	Exogenous expenditure share	1.4%*	
ω_{LTD}	Fraction of government debt maturing	0.0370*	

Note: Parameter values labeled with a * are calibrated such that the steady-state values of the variables listed in Table 2 correspond to their empirical counterparts. Given the target for θ and the calibration of the other parameters, the bond and capital utility weights χ_b do not matter for the linearized model dynamics and is therefore not reported. For the construction of τ_C, see B.2.

et al. (2016).

3.3 Estimated parameters

Tables 3 to 6 report the posterior mode and standard deviation of the estimated parameters for three variants of the POSA and the NOPOSA model. Columns headed "No STIEX" indicate that the respective estimation did not include data on forward rates, while "STIEX, $H = 8$" and "STIEX, $H = 12$" indicate the presence of forward rates in the set of observables, with a horizon H of 8 and 12 quarters, respectively. A couple of aspects are noteworthy regarding the NOPOSA model. Regarding the fiscal rule related parameters, in line with Coenen et al. (2013), I find a strong anticipation effect for lump-sum tax shocks, but only small anticipation effects for labor and consumption tax shocks (see Table 5, line five). All taxes respond to government debt.

Secondly, adding forward rates to the set of observables increases the persistence of the risk premium shock (see Table 4) as well as the degree of price and and especially nominal wage rigidity (see Table 3). The reason for the increase in the risk premium shock persistence is presumably that the model uses the risk premium shock to jointly match the observed combination of a downward trend of the forward curve over time (see Figure 6) with an absence of an acceleration of inflation or

Table 2: Empirical targets

Empirical target	Model counterpart	NOPOSA	POSA	Data	Source
Annualized Real GDP growth per capita	$(\gamma)^4 - 1$	1.3%		1.3%	AWM database
Annualized GDP deflator inflation rate	$(\Pi)^4 - 1$	3.2%		3.2%	AWM database
Annualized real short-term interest rate	$\left(\frac{R}{\Pi}\right)^4 - 1$	2.1%		2.1%	short term interest rate-GDP defl. inflation
Private investment share	$\frac{i}{y}$	18.7%		18.7%	AWM and EA fiscal database
Government expenditure share	$\frac{g}{y}$	23.5%		23.5%	AWM and EA fiscal database
Net exports plus inventory investment GDP share	$\frac{ex}{y}$	1.4%		1.4%	AWM database
Government debt-to-GDP ratio	$\frac{B_{G,L}}{4PY}$	66.2%		66.2%	AWM and EA fiscal database
Average maturity of outstanding gov. debt, years	$\frac{1}{4\omega_{LTD}}$	6.8		6.1	OECD and IMF fiscal monitor
Labor tax revenue-to-GDP-ratio	$\frac{\tau_N w}{y}$	12.3%		12.3%	AWM and EA fiscal database
Employee-social-security-contributions-to-GDP-ratio	$\frac{\tau_{w,h} N w}{y}$	8.2%		8.2%	AWM and EA fiscal database
Employer-social-security-contributions-to-GDP-ratio	$\frac{\tau_{w,f} N w}{y}$	7.8%		7.8%	AWM and EA fiscal database
Discounting wedge	$\theta = \frac{\beta}{\gamma}\frac{R}{\Pi}$	1	0.96	0.96	See Section Rannenberg (2019).

Note: All empirical targets directly obtained from the data are 1980-2019 or the longest available subsample. For more details on the data sources see B.

economic activity relative to trend, and indeed a decrease during the Great Recession. By contrast, the expansionary anticipated monetary policy shocks would not be able to deliver this combination (and indeed have ambiguous effects on the forward interest rate, as we shall see). However, rendering the persistent decline of GDP relative to trend during the great recession more forecastable for wage and price setters (and thus to a lesser extent a sequence of surprises) in itself tends to increase the endogenous decline in the real wage and inflation generated by the model, which is why the estimated degree of nominal rigidity as measured by the Calvo parameters increases. The marginal cost (wage markup) coefficient of the price (wage) Phillips curve in equation (2) (in equation 12) implied by the parameter estimates in the absence of forward rates, $H = 8$ and $H = 12$ equals 0.0015 (0.008), 0.001 (0.0045) and 0.0003 (0.0026), respectively.[9] Finally, the investment adjustment cost curvature increases, and there is a strong decline in the output growth coefficient of the monetary policy rule.

[9] The price and wage markup coefficients are given by $\kappa_p = \frac{(1-\omega_p)(1-\omega_p\beta)}{\omega_p(\mu_p-1)\epsilon_p+1}$ and $\kappa_w = \frac{(1-\omega_w)(1-\beta\omega_w)}{\omega_w(\mu_w-1)\epsilon_w+1}$,respectively.

Table 3: Estimated parameters: Structural

				Posterior distribution NOPOSA						Posterior distribution POSA					
	Prior distribution			No STIEX		STIEX, H=8		STIEX, H=12		No STIEX		STIEX, H=8		STIEX, H=12	
Parameter name	Shape	Mean	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.
h, Habit formation	BETA	0.70	0.10	0.65	0.04	0.73	0.03	0.77	0.03	0.63	0.04	0.70	0.03	0.66	0.03
ξ_I, Inv. Adj. cost	NORMAL	4.00	0.75	6.47	0.94	8.61	1.00	7.94	0.97	5.27	0.85	6.05	0.86	5.78	0.83
ψ, utilization cost	BETA	0.50	0.15	0.77	0.08	0.74	0.10	0.77	0.08	0.67	0.11	0.62	0.12	0.62	0.11
Φ, fixed cost	NORMAL	1.25	0.13	1.65	0.09	1.70	0.10	1.76	0.10	1.74	0.09	1.79	0.10	1.80	0.09
ω_w, calvo wages	BETA	0.50	0.10	0.80	0.03	0.85	0.02	0.90	0.02	0.80	0.02	0.83	0.02	0.82	0.02
ω_p, calvo prices	BETA	0.50	0.10	0.90	0.02	0.91	0.02	0.98	0.00	0.90	0.02	0.91	0.02	0.94	0.01
ι_w, wage indexation	BETA	0.50	0.15	0.24	0.09	0.23	0.09	0.22	0.09	0.22	0.09	0.22	0.08	0.21	0.08
ι_p, price indexation	BETA	0.50	0.15	0.14	0.05	0.15	0.05	0.18	0.06	0.15	0.05	0.16	0.05	0.15	0.05
ϕ_π, TR: Inflation	NORMAL	1.50	0.25	1.39	0.22	1.50	0.23	1.55	0.24	1.41	0.22	1.55	0.24	1.52	0.24
ϕ_R, TR: Smoothing	BETA	0.75	0.10	0.91	0.02	0.96	0.01	0.97	0.00	0.92	0.01	0.97	0.01	0.97	0.01
ϕ_y, TR: Output	NORMAL	0.13	0.05	0.18	0.03	0.26	0.04	0.22	0.04	0.18	0.04	0.21	0.04	0.19	0.04
$\phi_{\Delta y}$, TR: Growth	NORMAL	0.13	0.05	0.19	0.03	0.05	0.01	0.07	0.01	0.17	0.03	0.05	0.01	0.08	0.02
$\bar{n}$, SS hours	NORMAL	0.00	2.00	-0.70	0.95	-0.34	1.12	1.87	1.37	0.60	0.67	1.15	0.84	1.44	0.96
ω_N, calvo employment	BETA	0.50	0.20	0.73	0.03	0.80	0.02	0.83	0.02	0.70	0.03	0.77	0.03	0.73	0.03
σ_b, POSA curvature	NORMAL	0.40								0.39	0.05	0.45	0.05	0.51	0.04
σ_K, POSA curvature	NORMAL	1.00								1.66	0.20	1.63	0.22	1.55	0.20
Marginal Density				-539.4		1212.5		2819.5		-529.7		1238.6		2869.9	

Note: Sample Period: 1980Q1-2019Q4. 1980Q1-1980Q4 was used as a training sample. The likelihood was evaluated over the 1981Q1-2019Q4 period. No STIEX: No interest rate expectations used in estimation. STIEX, H=8: Dataset contains interest rate expectations with a horizon of up to 8 quarters (i.e. H=8 in equation 22. STIEX, H=12: Dataset contains interest rate expectations with a horizon of up to 12 quarters (H=12 in equation 22).

Table 4: Estimated parameters: Exogenous processes, non-policy and contemporaneous monetary policy

				Posterior distribution NOPOSA						Posterior distribution POSA					
	Prior distribution			No STIEX		STIEX, H=8		STIEX, H=12		No STIEX		STIEX, H=8		STIEX, H=12	
Parameter name	Shape	Mean	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.
Std. innovations															
$\eta_{a,t}$, Technology	IG	0.10	2.00	0.48	0.05	0.69	0.10	0.74	0.10	0.42	0.05	0.59	0.09	0.49	0.06
$\eta_{risk,t}$, Risk premium	IG	0.10	2.00	0.22	0.02	0.18	0.02	0.13	0.01	0.26	0.03	0.24	0.03	0.20	0.02
$\eta_{EX,t}$, Ex. spending	IG	0.10	2.00	0.29	0.02	0.29	0.02	0.29	0.02	0.29	0.02	0.29	0.02	0.29	0.02
$\eta_{I,t}$, Investment	IG	0.10	2.00	0.60	0.06	0.55	0.06	0.58	0.06	0.67	0.06	0.65	0.06	0.64	0.06
$\eta_{p,t}$, Price markup	IG	0.10	2.00	0.14	0.01	0.15	0.01	0.15	0.01	0.15	0.01	0.15	0.01	0.15	0.01
$\eta_{w,t}$, Wage markup	IG	0.10	2.00	0.14	0.01	0.14	0.01	0.14	0.01	0.16	0.01	0.16	0.01	0.15	0.01
$\eta^0_{R,t}$, Mpol	IG	0.10	2.00	0.10	0.01	0.05	0.00	0.05	0.00	0.10	0.01	0.05	0.00	0.05	0.00
$\eta_{obj,t}$, Infl. Target	IG	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AR(1) coefficients															
ρ_a, Technology	BETA	0.50	0.20	0.97	0.00	0.97	0.01	0.99	0.01	0.96	0.01	0.95	0.01	0.96	0.01
ρ_{risk}, Risk premium	BETA	0.50	0.20	0.95	0.01	0.97	0.00	0.00	0.00	0.95	0.01	0.97	0.01	0.98	0.01
ρ_{EX}, Ex. Spending	BETA	0.50	0.20	1.00	0.00	0.99	0.01	0.99	0.01	0.98	0.01	0.98	0.01	0.98	0.01
ρ_I, Investment	BETA	0.50	0.20	0.28	0.07	0.35	0.09	0.28	0.09	0.22	0.07	0.25	0.08	0.28	0.08
ρ_p, Price markup	BETA	0.50	0.20	0.91	0.02	0.91	0.02	0.92	0.01	0.91	0.01	0.91	0.01	0.92	0.01
ρ_w, Wage markup	BETA	0.50	0.20	0.94	0.01	0.93	0.02	0.92	0.03	0.96	0.01	0.96	0.01	0.97	0.01
ρ_R, Mpol	BETA	0.50	0.20	0.48	0.05	0.55	0.07	0.58	0.07	0.48	0.05	0.49	0.07	0.49	0.06
ρ_{obj}, Mpol	BETA	0.50	0.20	0.72	0.05	0.73	0.06	0.73	0.07	0.73	0.05	0.75	0.06	0.77	0.06
Other															
v_p, MA Price markup	BETA	0.50	0.20	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.01
v_p, MA Wage markup	BETA	0.50	0.20	0.07	0.03	0.06	0.03	0.04	0.02	0.05	0.02	0.04	0.02	0.04	0.02
$\rho_{a,EX}$	NORMAL	0.50	0.25	0.12	0.05	0.06	0.04	0.04	0.04	0.14	0.06	0.09	0.05	0.12	0.05

Note: See the note below Table 3 for the meaning of the labels and other details about the estimation.

Table 5: Estimated parameters: Fiscal rules

				Posterior distribution NOPOSA						Posterior distribution POSA					
	Prior distribution			No STIEX		STIEX, H=8		STIEX, H=12		No STIEX		STIEX, H=8		STIEX, H=12	
Parameter name	Shape	Mean	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.
Std. innov.															
$\eta_{\tau,C}$, CT	IG	0.10	2.00	0.49	0.04	0.49	0.04	0.49	0.04	0.47	0.04	0.46	0.04	0.46	0.04
AR(1) coef.															
ρ_{τ}, LST	BETA	0.50	0.20	0.94	0.03	0.93	0.03	0.92	0.03	0.96	0.02	0.96	0.02	0.96	0.02
Ant. innov.															
ϕ_{τ}, LST	BETA	0.50	0.20	0.79	0.05	0.79	0.05	0.79	0.05	0.83	0.05	0.84	0.05	0.83	0.05
Debt resp.															
$\phi_{b,\tau}$, LST	GAMMA	0.50	0.20	0.14	0.05	0.13	0.04	0.12	0.03	0.14	0.06	0.11	0.03	0.07	0.02
Output resp.															
$\phi_{y,\tau}$, LST	NORMAL	0.00	0.20	-0.07	0.05	-0.06	0.05	-0.07	0.05	-0.07	0.05	0.00	0.06	0.03	0.05

Note: See the note below Table 3 for the meaning of the labels and other details about the estimation.

The broad direction of these changes are in line with the findings of Rannenberg (2020), who compares parameter estimates from estimation with forward rates in the dataset, following the same approach as adopted here, to an estimation without forward rates, and Lindé et al. (2016), both for the US economy. Lindé et al. (2016) compare parameter estimates disregarding the ZLB with an estimation where during the ZLB period, the model is forced to match OIS rates regarding the federal funds rate in one to 12 quarters ahead. However, the increase in risk premium shock persistence that they find is even stronger (their AR(1) coefficient increases from 0.41 to 0.85) and the increase in nominal rigidity is concentrated in price setting.

With POSA, in the absence of forward rates from the dataset, the parameter estimates are overall close to the NOPOSA case. The estimated persistence of the risk premium shock is larger and the degree of habit formation and investment adjust cost correspondingly lower. The effect of adding forward rates differs for some parameters from the NOPOSA model. Specifically, the increase in price and especially wage stickiness is much smaller, as well as the increase in the investment adjust cost curvature.[10] Hence it appears that with POSA, the model relies less on these nominal and real rigidities to attenuate the effect of the observed forward rates. The parameters of the AR(1) processes of the anticipated monetary policy shocks ε_t^i are very close to the NOPOSA case, except for $i = 7$.

Regarding overall fit as measured by the marginal data density, without interest rate expectations in the set of observables the empirical fit of the POSA and NOPOSA model is similar. However, the relative fit of the POSA model dramatically improves once interest expectations are observed. For $H = 8$, the difference between the two models amounts to 23.6 log points. Once the horizon of the included expectations increases to 12 quarters ($H = 12$), the difference between the POSA and NOPOSA model rises to 35.9 log points (see Table 3). This finding and the fact that the posterior mode of σ_b increases when we ad interest rate expectations suggest that the data on average prefers the attenuation of consumption smoothing and the wealth effect associated with POSA to the NOPOSA model.

4 Impulse response functions and the forward guidance puzzle

I now discuss the IRFs generated by the models estimated without interest rate expectations in the dataset, and those estimated interest rate expectations with horizon $H = 12$. As can be seen from Figure 1, in the absence of interest rate expectations from the dataset (the black lines), the responses of the NOPOSA and POSA models to the standard shocks known from Smets and Wouters (2007) type DSGE models are generally similar. If there are differences, they are sometimes the

[10]Using the formula defined in the previous footnote, the price (wage) markup coefficients are given by 0.0012 (0.0085), 0.0009 (0.0065) and 0.0004 (0.0069), in the absence of forward rates, $H = 8$ and $H = 12$, respectively.

Table 6: Estimated parameters: Anticipated monetary policy shocks

				Posterior distribution NOPOSA				Posterior distribution POSA			
	Prior distribution			STIEX, H=8		STIEX, H=12		STIEX, H=8		STIEX, H=12	
Parameter name	Shape	Mean	Std.	Mode	Std.	Mode	Std.	Mode	Std.	Mode	Std.
Std. innov.											
$\eta^1_{R,t}$	IG	0.1	2.0	0.053	0.003	0.053	0.003	0.054	0.003	0.054	0.003
$\eta^2_{R,t}$	IG	0.1	2.0	0.044	0.003	0.045	0.003	0.045	0.003	0.046	0.003
$\eta^3_{R,t}$	IG	0.1	2.0	0.037	0.002	0.038	0.002	0.037	0.002	0.036	0.002
$\eta^4_{R,t}$	IG	0.1	2.0	0.047	0.003	0.048	0.003	0.047	0.003	0.048	0.003
$\eta^5_{R,t}$	IG	0.1	2.0	0.048	0.003	0.049	0.003	0.046	0.003	0.046	0.003
$\eta^6_{R,t}$	IG	0.1	2.0	0.020	0.001	0.021	0.001	0.020	0.001	0.020	0.001
$\eta^7_{R,t}$	IG	0.1	2.0	0.025	0.003	0.024	0.002	0.023	0.002	0.022	0.002
$\eta^8_{R,t}$	IG	0.1	2.0	0.022	0.002	0.046	0.003	0.021	0.001	0.045	0.003
$\eta^9_{R,t}$	IG	0.1	2.0			0.039	0.003			0.037	0.002
$\eta^{10}_{R,t}$	IG	0.1	2.0			0.014	0.001			0.014	0.001
$\eta^{11}_{R,t}$	IG	0.1	2.0			0.008	0.001			0.008	0.001
$\eta^{12}_{R,t}$	IG	0.1	2.0			0.009	0.001			0.008	0.001
AR(1) coef.											
ρ^1_R, AR(1) $\varepsilon^1_{R,t}$	BETA	0.5	0.2	0.04	0.03	0.04	0.03	0.04	0.03	0.05	0.03
ρ^2_R,AR(1) $\varepsilon^2_{R,t}$	BETA	0.5	0.2	0.73	0.04	0.73	0.03	0.71	0.03	0.69	0.03
ρ^3_R, AR(1) $\varepsilon^3_{R,t}$	BETA	0.5	0.2	0.06	0.05	0.07	0.05	0.05	0.04	0.06	0.05
ρ^4_R, AR(1) $\varepsilon^4_{R,t}$	BETA	0.5	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
ρ^5_R, AR(1) $\varepsilon^5_{R,t}$	BETA	0.5	0.2	0.30	0.11	0.34	0.04	0.28	0.05	0.28	0.05
ρ^6_R, AR(1) $\varepsilon^6_{R,t}$	BETA	0.5	0.2	0.47	0.62	0.05	0.04	0.11	0.08	0.10	0.08
ρ^7_R, AR(1) $\varepsilon^7_{R,t}$	BETA	0.5	0.2	0.82	0.05	0.86	0.04	0.79	0.04	0.60	0.11
ρ^8_R, AR(1) $\varepsilon^8_{R,t}$	BETA	0.5	0.2	0.78	0.04	0.03	0.03	0.79	0.04	0.02	0.02
ρ^9_R, AR(1) $\varepsilon^9_{R,t}$	BETA	0.5	0.2			0.07	0.02			0.05	0.02
ρ^{10}_R, AR(1) $\varepsilon^{10}_{R,t}$	BETA	0.5	0.2			0.88	0.03			0.91	0.02
ρ^{11}_R, AR(1) $\varepsilon^{11}_{R,t}$	BETA	0.5	0.2			0.94	0.02			0.91	0.03
ρ^{12}_R, AR(1) $\varepsilon^{12}_{R,t}$	BETA	0.5	0.2			0.94	0.02			0.96	0.03

Note: $\varepsilon^i_{R,t}$ denote the anticipated monetary policy shocks (see equation **??**) and $\eta^i_{R,t}$ the corresponding shock innovations. See the note below Table 3 for the meaning of the labels and other details about the estimation.

consequence of differences in parameter estimates unrelated to POSA, as is illustrated by the IRF of the POSA model with all (non-POSA related) parameters set to the NOPOSA (compare the red solid and the red crossed line). For instance, the exogenous expenditure and the risk premium shock have a smaller estimated persistence in the POSA model.

For the models estimated with forward rates in the dataset, the response to the technology shock continues to differ persistently and substantially with POSA even after eliminating the influence of differences in non-POSA related parameters. Specifically, in the NOPOSA model, the consumption increase is larger relative to the observed investment increase, especial during the first two years. The reason is that the TFP shock is extremely persistent and thus triggers strong permanent-income effects in the NOPOSA model. By contrast, POSA attenuates the permanent-income effect due to the aforementioned attenuation of consumption smoothing with POSA, as well as the wealth effect due to the countercyclical response of government debt. Therefore the shock triggers a larger decline in the policy rate.

Turning to the anticipated monetary policy shocks $\varepsilon^i_{R,t}$ (Figures 2 and 3), first of all, note that their stimulative effect of an anticipated causes on on-impact increase in the policy rate, and a rising trajectory up until quarter i. Moreover, in the NOPOSA model, for $i = 2, 7$ and $i \geq 10$, the dynamic stimulative effect of the anticipated monetary policy shock is so strong that when the shock arrives in quarter $i + 1$, the interest rate does not actually turn negative immediately, and may remain positive for between one quarter and almost two years. The fact that an expansionary forward guidance policy may actually increase forward interest rates was already noted by de Graeve et al. (2014).

Furthermore, with POSA the response of GDP and its components is weaker for all i. This is mainly due to POSA rather than to differences in the non-POSA related estimated parameters, as the red dotted and red crossed lines are typically on top of each others. The one exception is $i = 7$, where the estimated persistence parameter ρ^i_R is smaller with POSA. Due to the smaller stimulative effect of the anticipated monetary policy shocks, the interest rate trajectory they cause is always lower with POSA, and the effect of the shock on the interest turns negative at most 3 quarters after the occurrence of the shock.

We now examine the effect of fixing the short term interest rate below its steady state value for a fixed number of quarters, allowing it to adjust according to the model's policy rule thereafter (see Figure 4). This type of experiment is frequently used to examine the effect of forward guidance policies in a model. In the NOPOSA model, the effect of forward guidance is very strong. For instance, even if interest rate expectations are included as observables in the estimation of the model, the peak GDP effect of a 12 quarter peg of the interest rate of 0.2 percentage points below its steady state equals 1% (see the black dotted line). By contrast, with POSA the peak effect equals less than half of this value, with consumption and investment contributing roughly equally to the attenuation (compare the magenta dotted to the black dotted line). To illustrate the importance of the estimated wealth effect of government debt for the attenuation forward guidance, the graph shows that, for $\sigma_b = 0$, the response of GDP and its components is very close to the NOPOSA model (compare the magenta crossed and the black dotted line).

Finally, note with all non-POSA related parameters set to their values in the POSA model, the effect of forward guidance would be much larger still in the NOPOSA model. Hence the stronger estimated nominal and real rigidities (i.e. a higher investment adjustment cost curvature and higher degree of habit formation) compensate to some extent for the absence of POSA.

5 Out of sample forecasting[under construction]

6 Contribution of forward guidance to economic activity and inflation

Figure 7 displays the historical decomposition of the deviation of output from trend for the NOPOSA model. To facilitate the exposition, we have grouped the shocks. The anticipated monetary policy shocks (i.e. the $\eta^i_{R,t}$ for $i > 0$) are represented by the dark green bar. As can be obtained from Figure 7, the impact of the anticipated monetary policy shocks on economic activity is negative at the beginning of the 2000s, and then again over 2008Q4-2016Q4. Those phases of negative contributions partly reflect the more positive slope of the forward curve (see Figure6), which the model attempts to match via expansionary shocks at shorter horizons and contractionary anticipated shocks at longer horizons (see also Figures 9 and 10). By contrast, a flattening forward curve tends to be associated with less contractionary anticipated monetary policy shocks.

Explicit forward guidance in the Euro Area started in July 2013, strengthened in January 2014 and January 2015 (APP). These announcements are associated with a change in the combined contribution of the anticipated monetary policy shocks from -8.9% to -4.9%. Thus we observe increase of about 4% which occurs after the start of forward guidance by the governing council. The contribution of the anticipated monetary policy shocks to year-on-year inflation increases by 0.2 percentage points over the same period. Note however that these figures should be considered upper bounds, as the negative contributions of the anticipated shocks post 2013Q2 may partly reflect the ELB, which our estimation does not explicitly control for, and which might have become less of a constraint as the economy recovered during 2013-2019. At the same time, it is worthwhile noting that that main drivers of the downward trend of both short and long-term interest rates is private sector aggregate demand in the form of the risk-premium shock due rather than the anticipated monetary policy shocks (see Figure 10). The reason is that, unlike the monetary policy shock, the risk-premium shock can deliver the aforementioned combination of a downward trend of the forward curve over time with weak GDP growth and inflation. Furthermore, as discussed in Section 4, the impact of the anticipated monetary policy shocks on the forward interest rate becomes in fact ambiguous for $i \geq 10$.

With POSA, the increase in the combined contribution of anticipated monetary policy shock to GDP and inflation post 2013Q2 equals about 1.9%, and 0.1 percentage point, respectively. Unlike in the NOPOSA model, the impact of the forward guidance shock on $E_t\hat{R}_{t+12}$ becomes less positive as the anticipated monetary policy shocks become more expansionary, with the change post 2013Q2 cumulating to -1.3 percentage points. This direction is in line with the discussion of the IRFs to the anticipated monetary policy shocks in Section 4.

A drawback of our model solution method is that it does not explicitly treat the ELB. Instead, to the extent that it is binding, the ELB constraint would be reflected in contractionary contemporaneous or anticipated monetary policy shocks. Since both inflation and GDP have recovered somewhat since 2014Q4, the less negative combined contribution of the anticipated monetary policy shocks over that period may partly reflect a less binding ZLB constraint.

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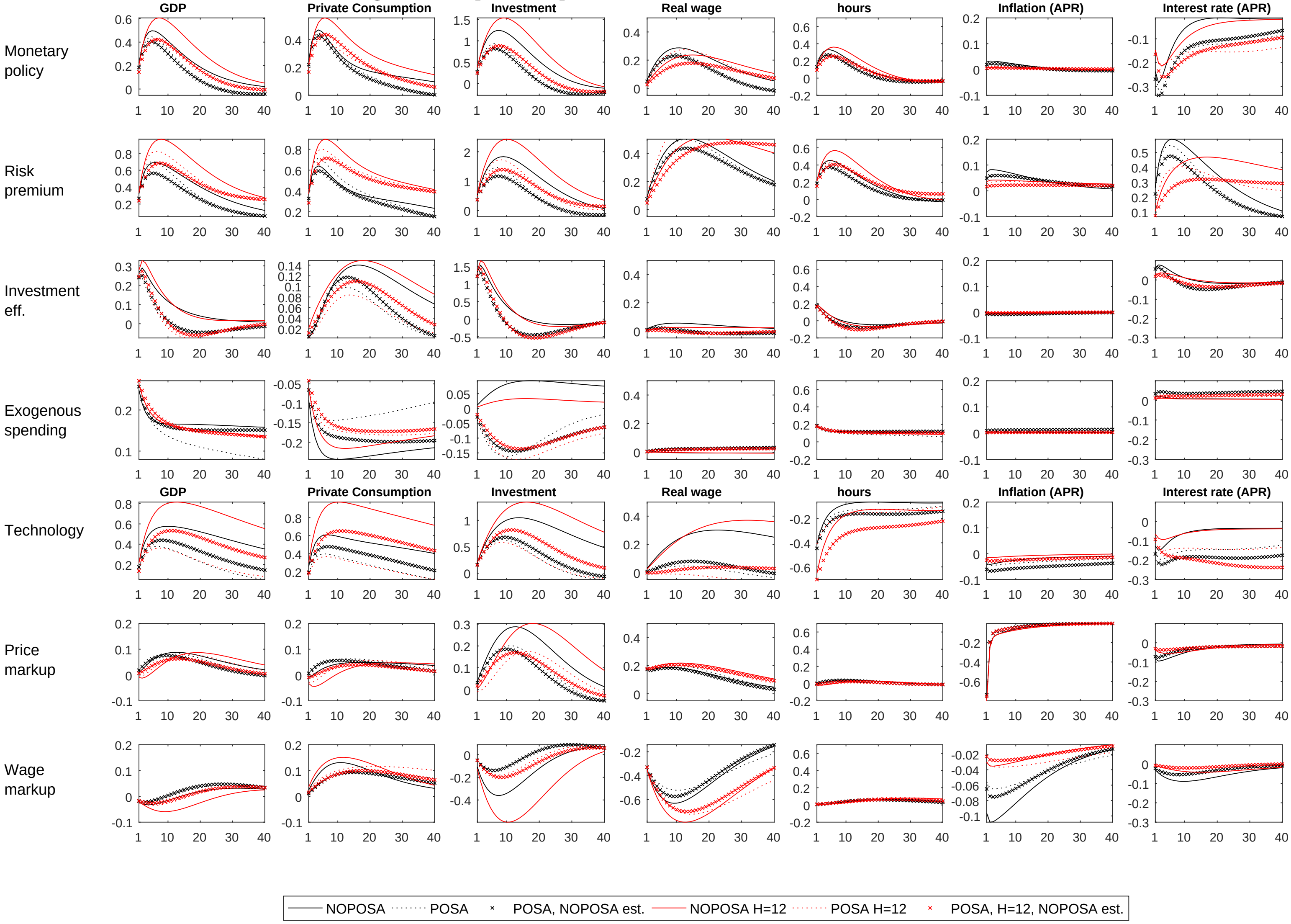
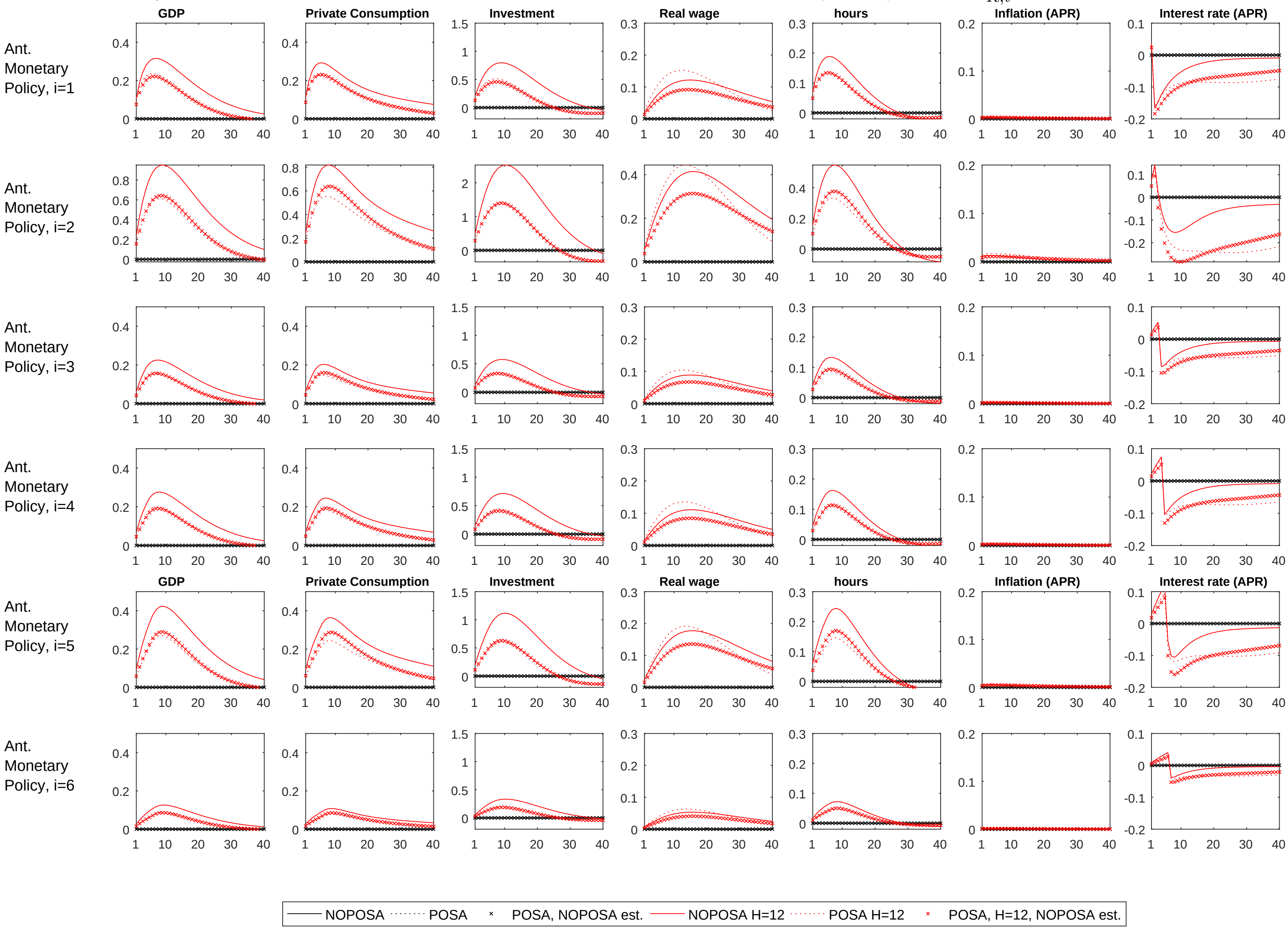
Figure 1: Impulse response functions - standard shocks



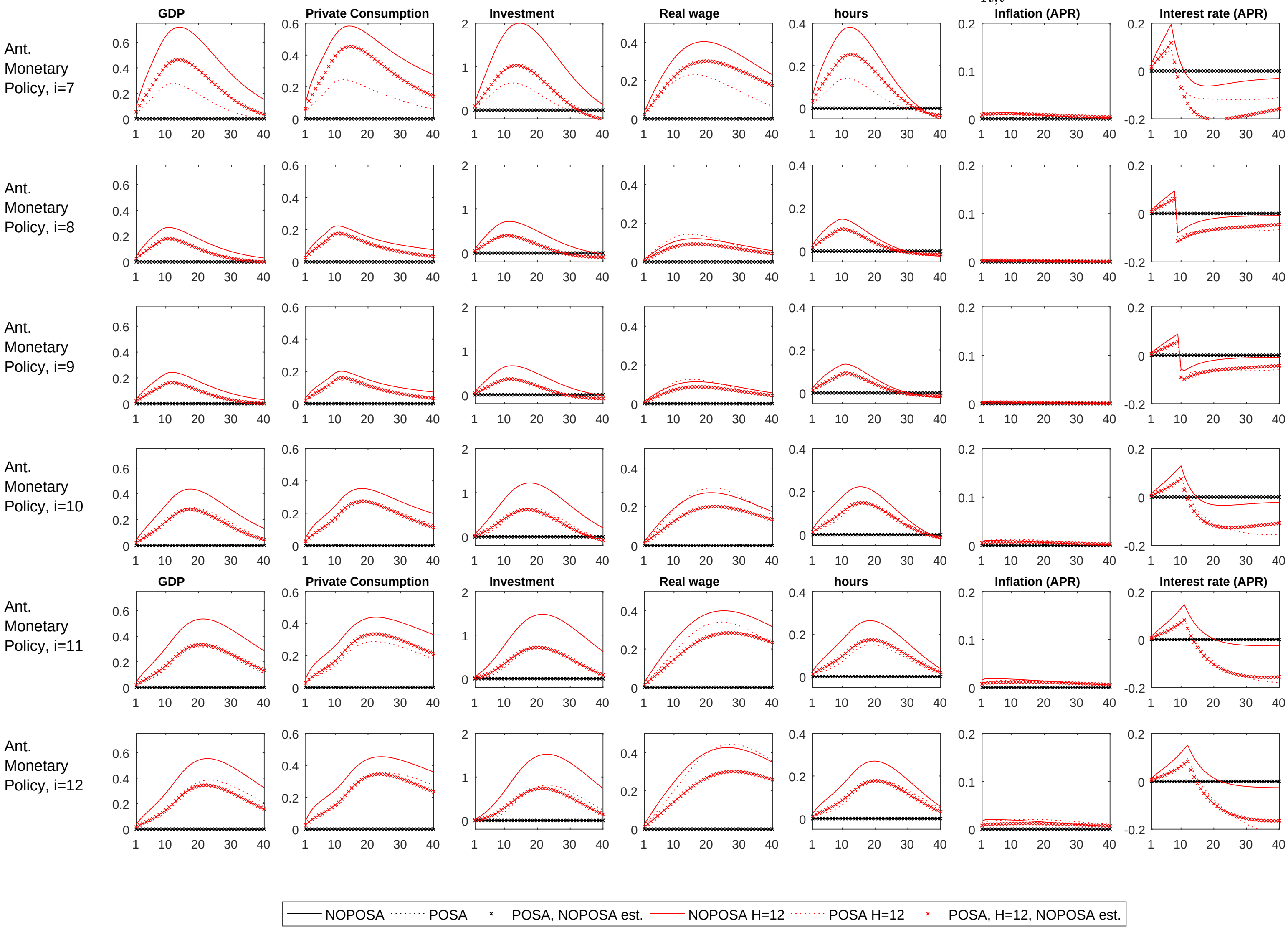
Note: This graph displays the Impulse response function to the indicated shock, based on the parameter estimates reported in Tables 3 to 6 in the columns labeled “NOSTIEX” and “STIEX, H=12”. IRFs labeled “POSA, NOPOSA est.” were computed setting $\theta = 0.96$ and σ_b and σ_K to their respective posterior modes, and setting the remaining parameters to the estimates from the NOPOSA model. Black lines are based on the parameter values from the respective “NOSTIEX” columns. Red lines are based on parameter values from the respective “STIEX, H=12” columns, i.e. forward rates were used in their estimation. All shocks are signed such that they generate an on-impact GDP increase, except for the wage and price markup shocks. The markup shocks display the response to a decrease in the respective markup.

Figure 2: Baseline - Impulse response functions to anticipated monetary policy shocks $\varepsilon^{i}_{R,t}$, $i = 1 - 6$



Note: See the note below Figure 1.

Figure 3: Baseline - Impulse response functions to anticipated monetary policy shocks $\varepsilon^{i}_{R,t}$, $i = 7 - 12$



Note: See the note below Figure 1.

Figure 4: Effect of an interest rate peg in the estimated models - Peak effects

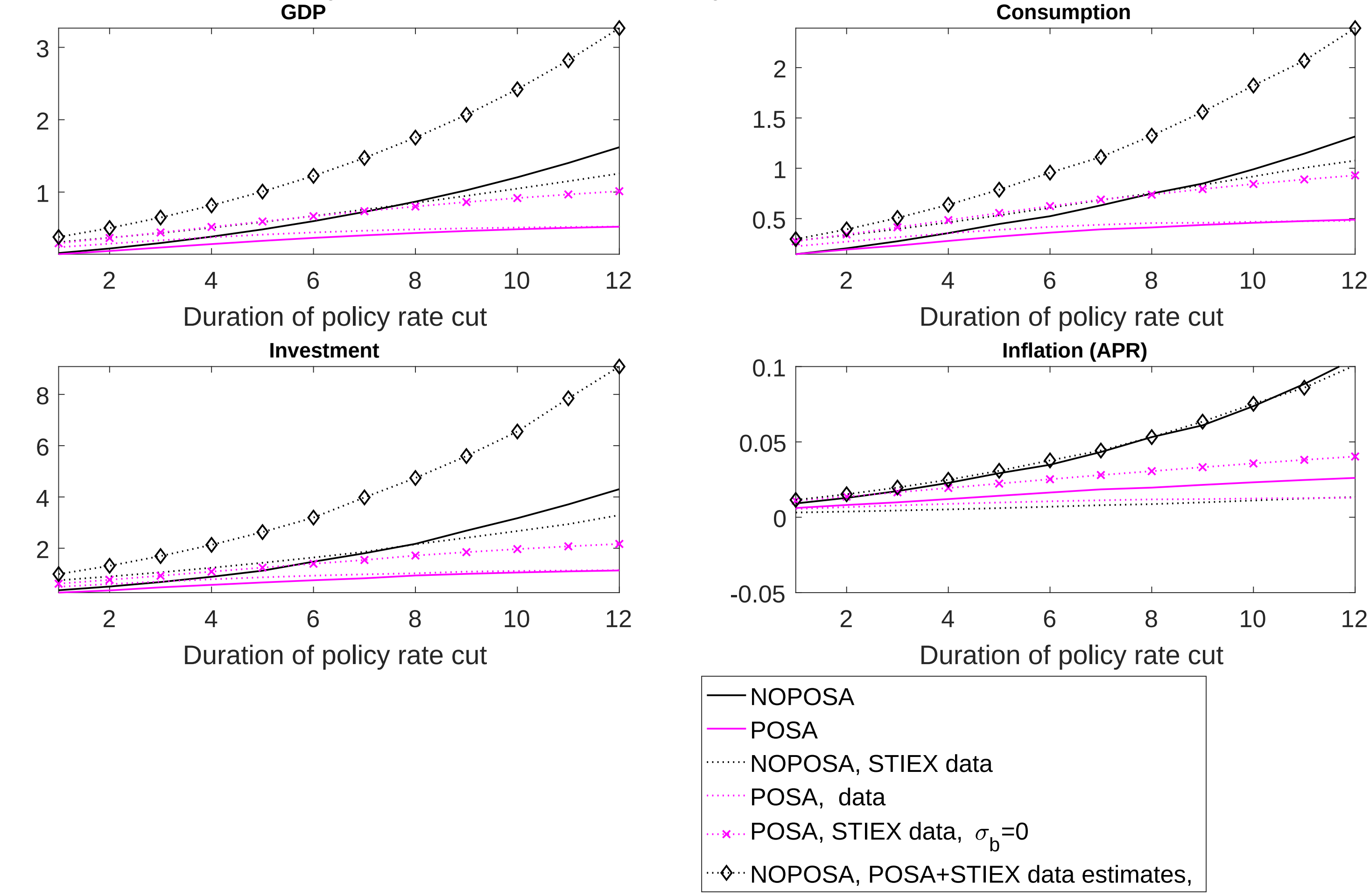


Figure 5: Dynamic effect of an 8 quarter interest rate peg in the estimated models

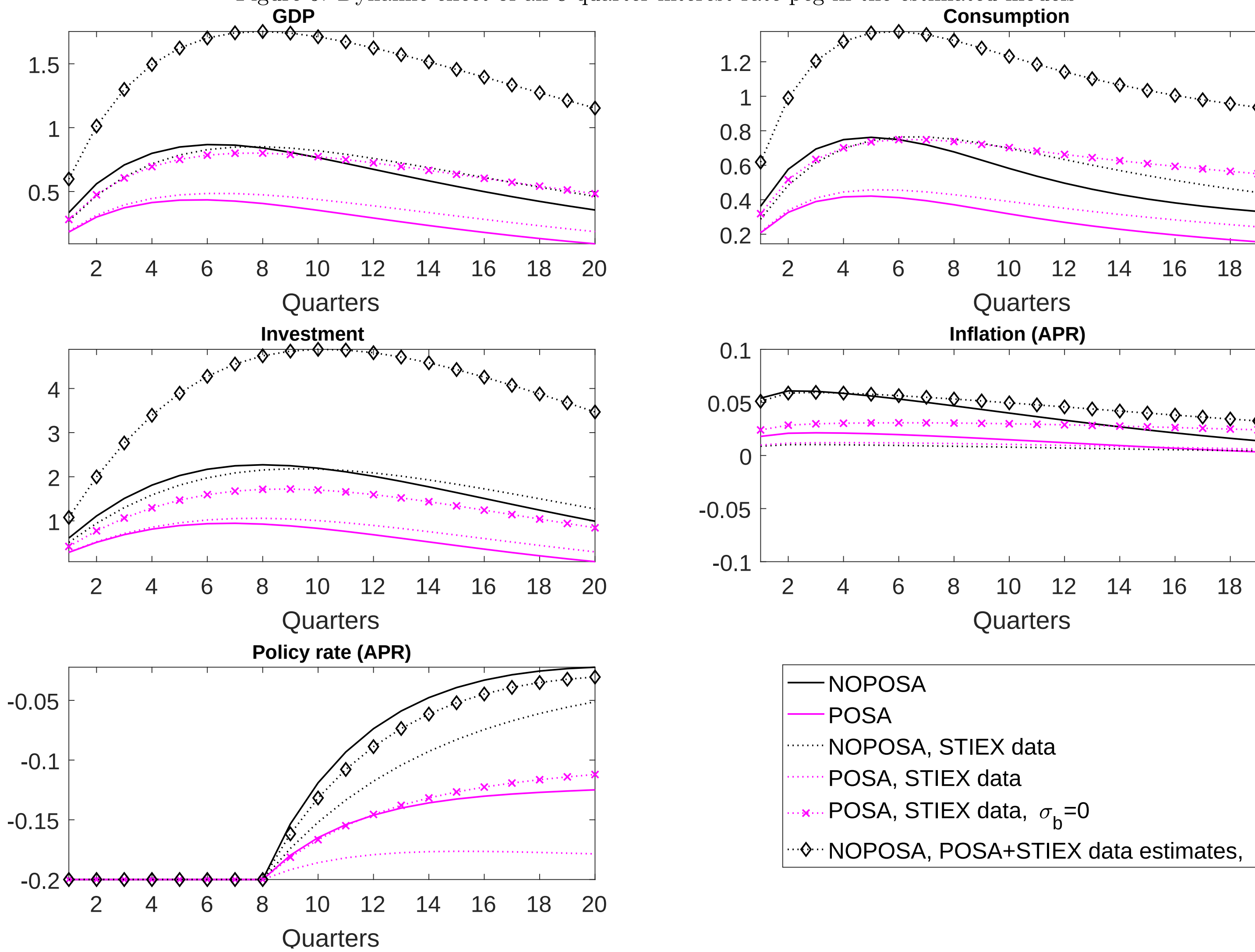


Figure 6: Forward curve

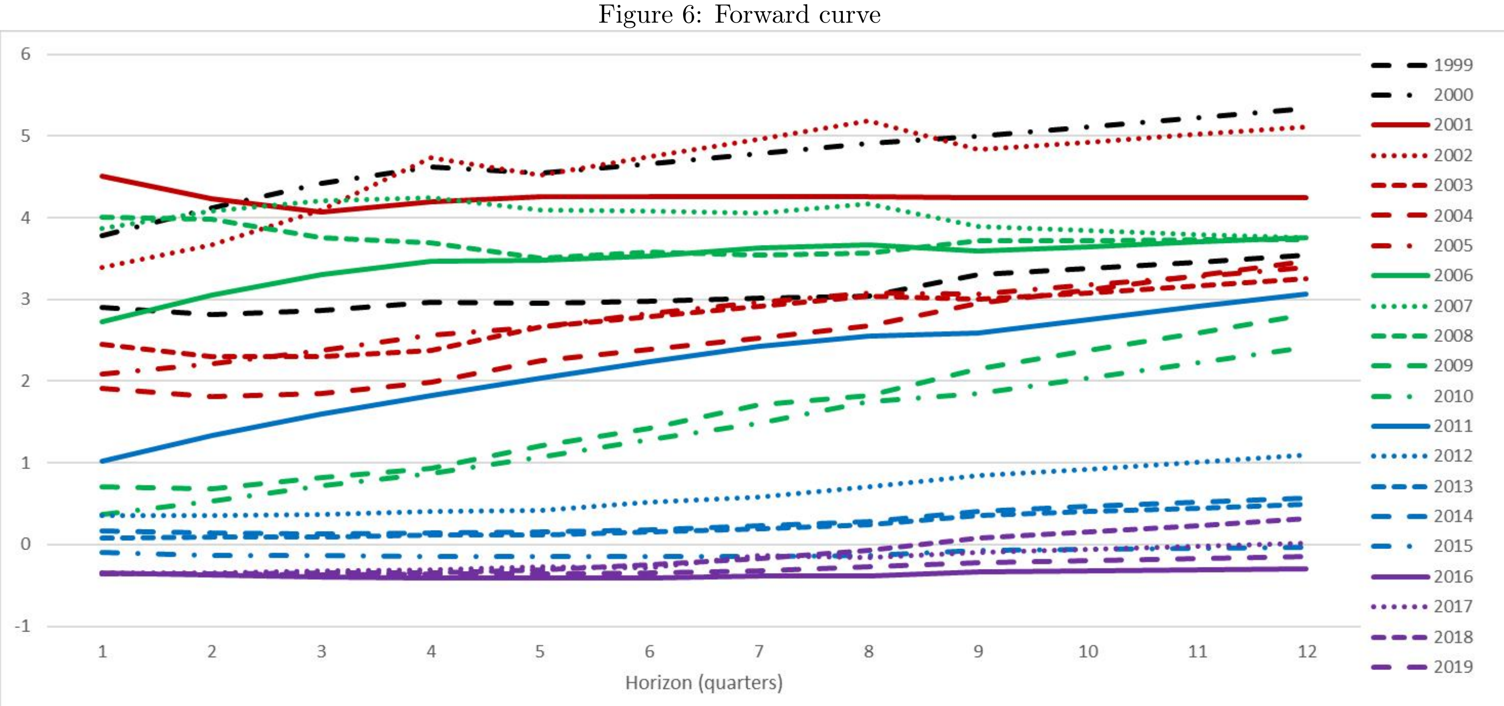
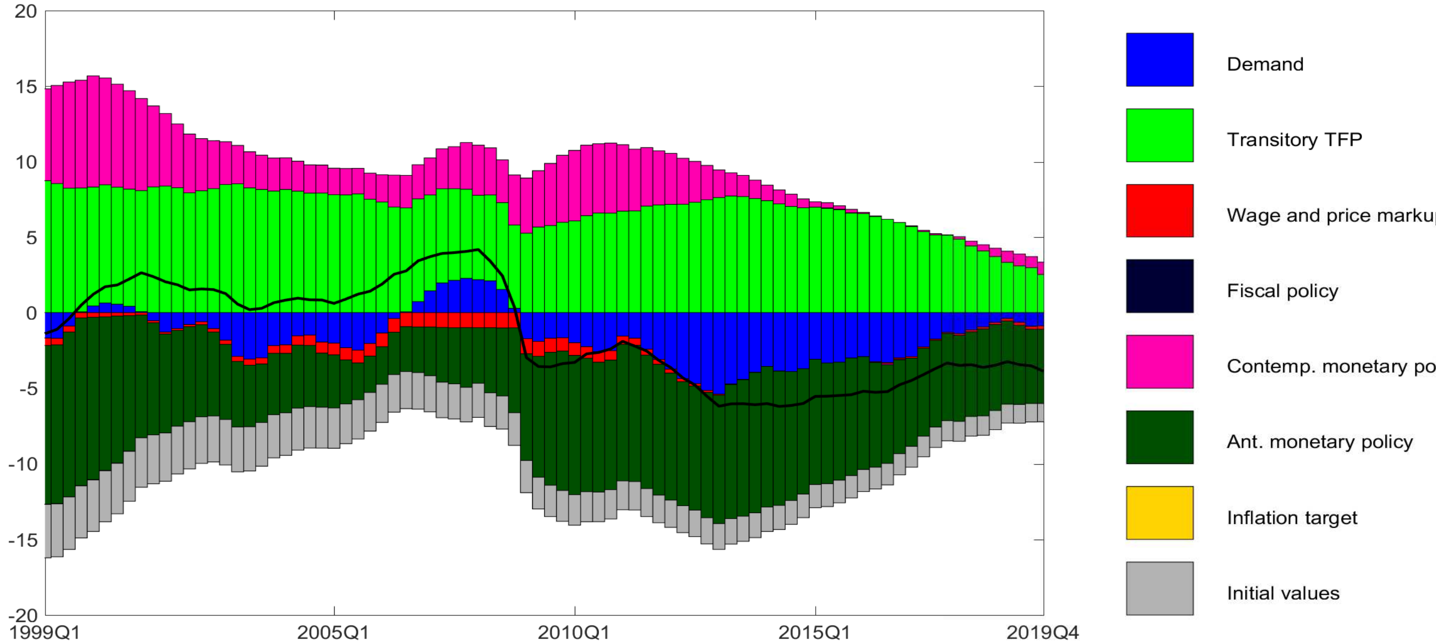
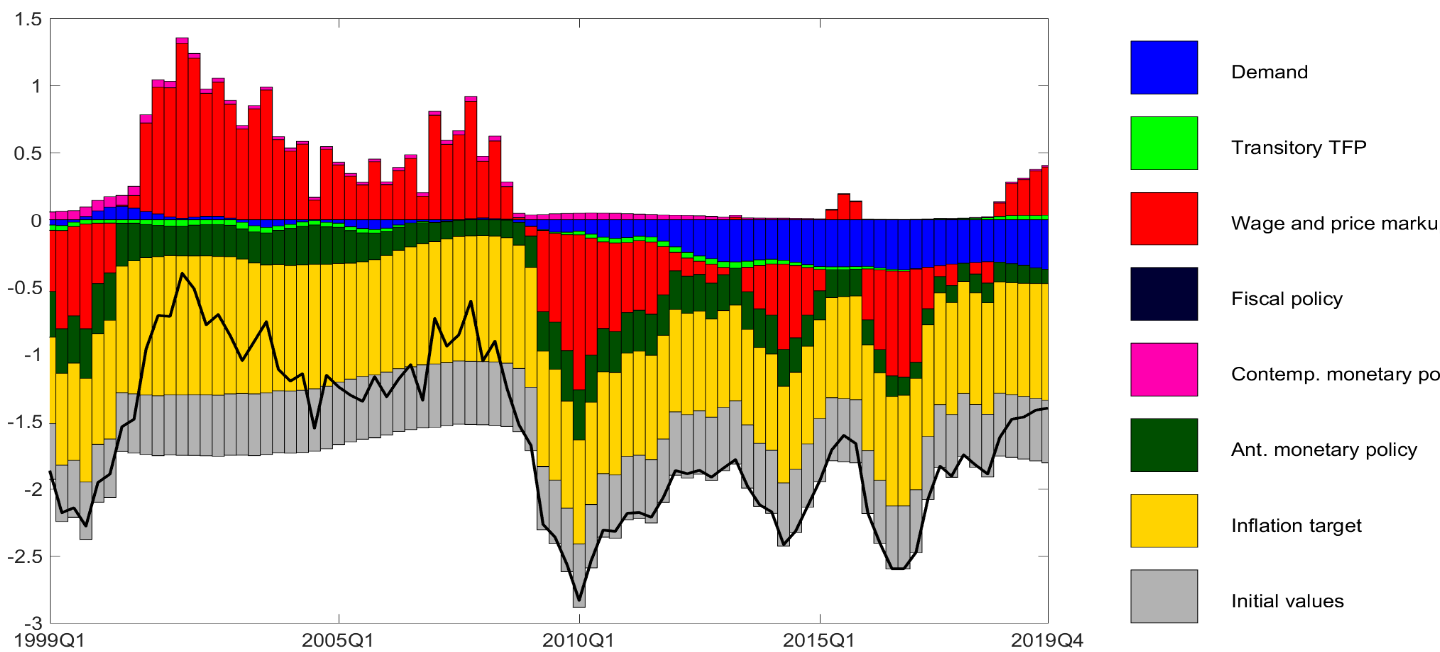


Figure 7: Historical decomposition, NOPOSA: GDP (level)



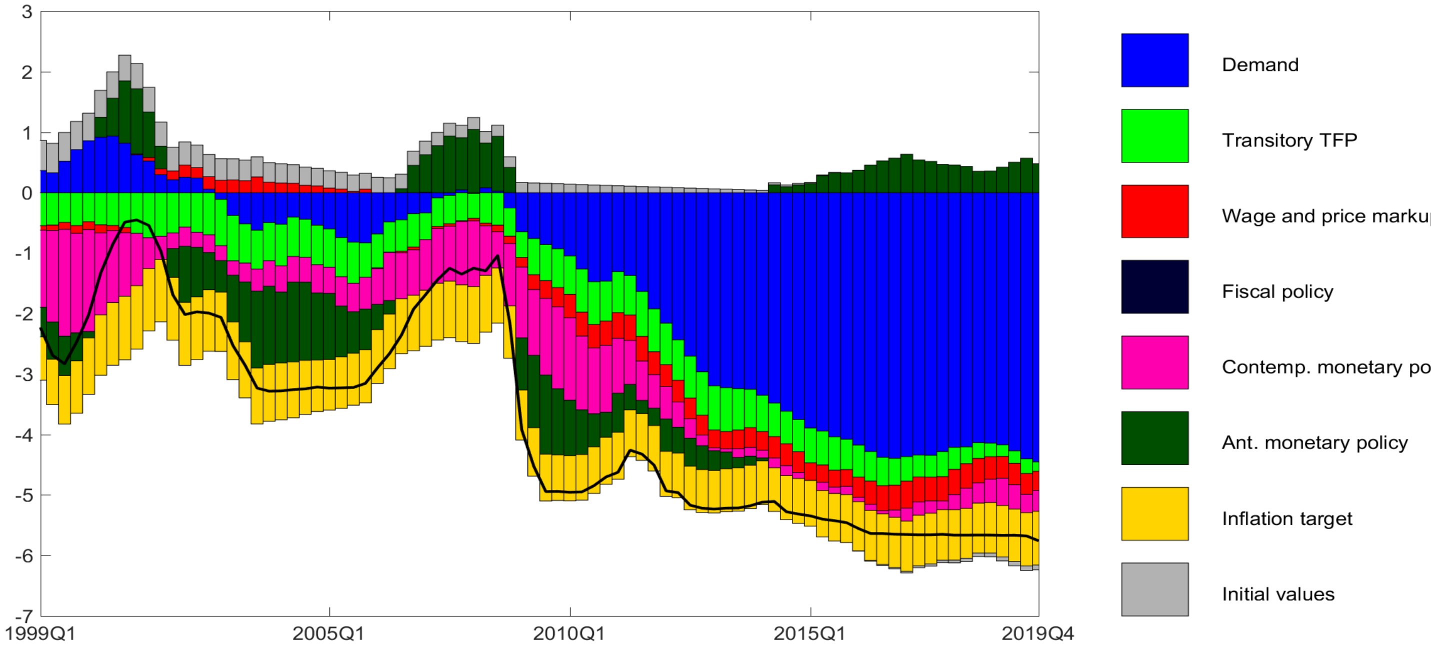
Note: This graph displays the historical decomposition of the NOPOSA model estimated with interest rate expectations in the dataset, with $H = 12$. The parameter estimates are as reported in Tables 3 to 6. "Demand": Risk premium ($\eta_{b,t}$), investment specific technology ($\eta_{I,t}$) and exogenous expenditure ($\eta_{EX,t}$) shocks. "Fiscal policy": lump sum tax ($\eta_{\tau,t}$), labor tax ($\eta_{\tau_w,t}$) and consumption tax ($\eta_{\tau_C,t}$) shocks. "Contemp. monetary policy": $\eta^0_{R,t}$, "Ant. monetary policy": $\eta^i_{R,t}$ for $i > 0$.

Figure 8: Historical decomposition, NOPOSA: Year-on-year-inflation



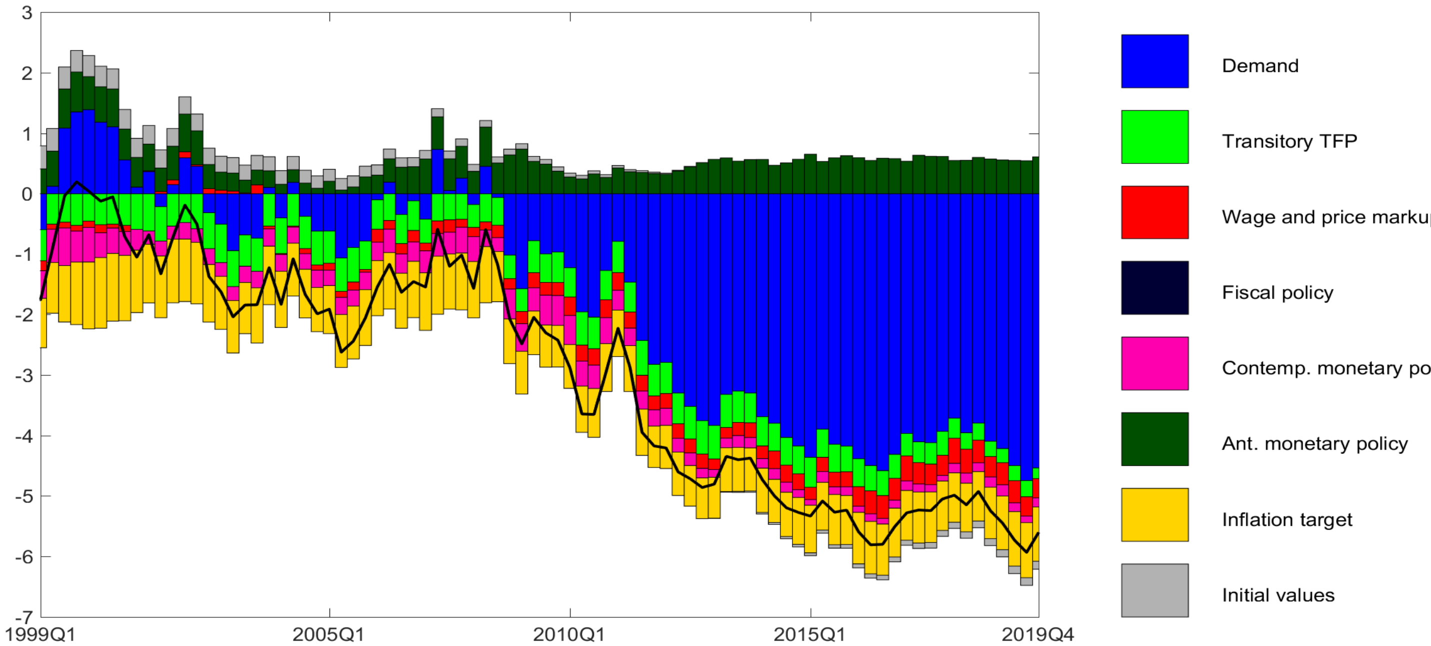
Note: This graph display the historical decomposition of the deviation of year-on-year inflation from its steady state $\hat{\Pi}_{t,t-3} = \hat{\Pi}_t + \hat{\Pi}_{t-1} + \hat{\Pi}_{t-2} + \hat{\Pi}_{t-3}$. For the definition of the shock groups and further information on the model used, see the note below Figure 7. The negative smoothed values of inflation throughout the displayed period displayed in the plot reflect the fact that the steady state inflation rate, which equals average of inflation across the sample, exceeds the inflation rate observed over the 1999-2019 period.

Figure 9: Historical decomposition, NOPOSA: STI_t



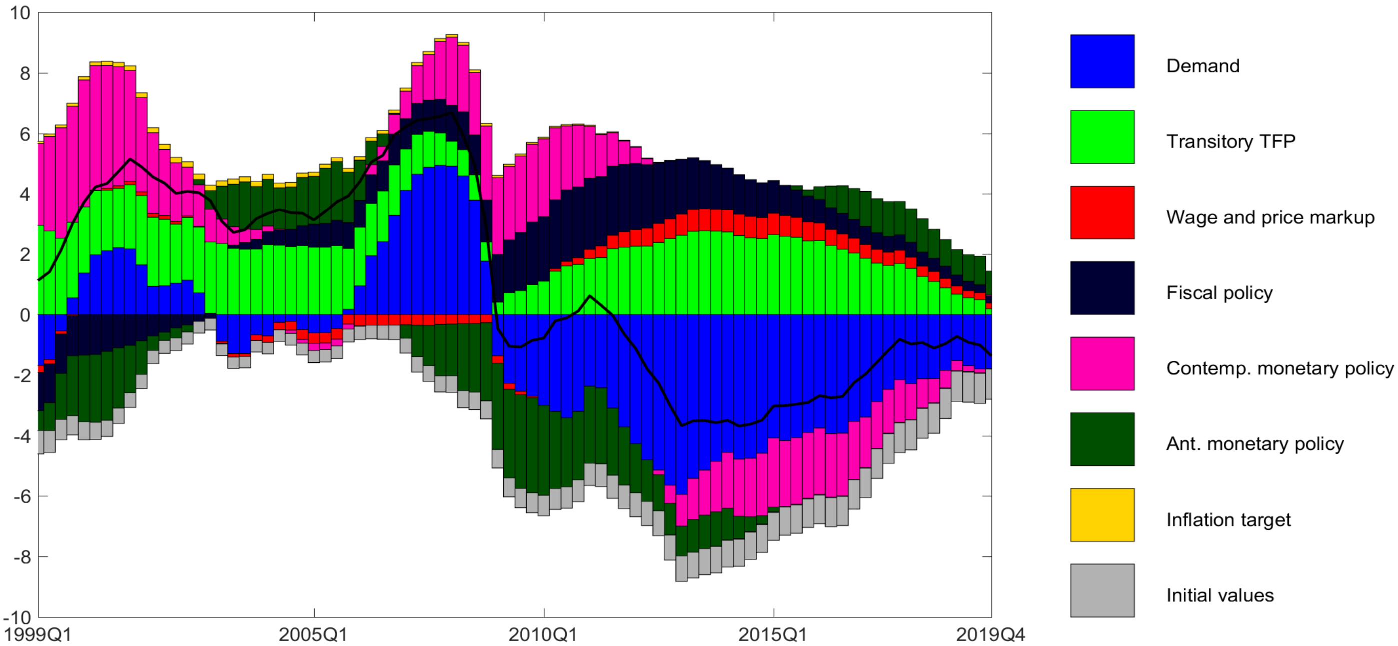
Note: For the definition of the shock groups and further information on the model used, see the note below Figure 7.

Figure 10: Historical decomposition, NOPOSA: $4E_t\hat{R}_{t+12}$



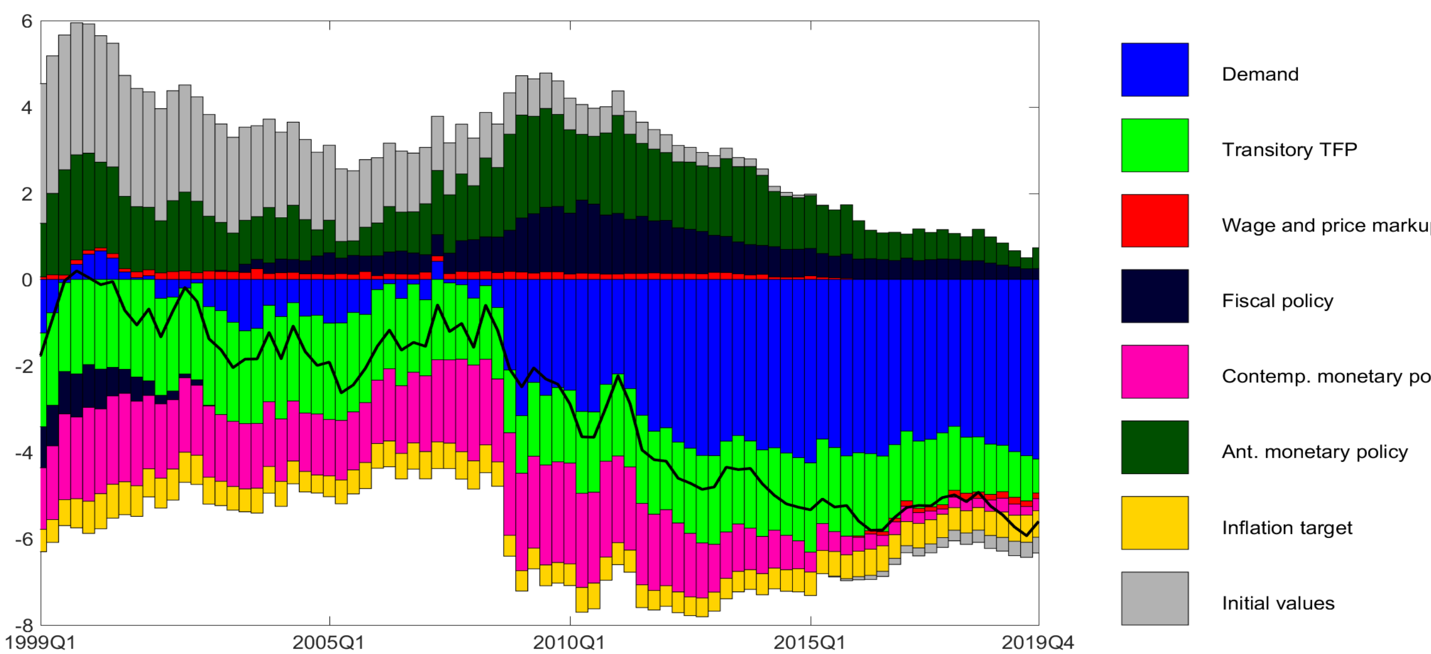
Note: For the definition of the shock groups and further information on the model used, see the note below Figure 7.

Figure 11: Historical decomposition, POSA: GDP (level)



Note: This graph displays the historical decomposition of GDP obtained from the POSA model estimated with interest rate expectations in the dataset, with $H = 12$. The parameter estimates are as reported in Tables Tables 3 to 6. For the definition of the shock groups, see the note below Figure 7.

Figure 12: Historical decomposition, POSA: $4E_t\hat{R}_{t+12}$



Note: For the definition of the shock groups and further information on the model used, see the note below Figure 7.

A Model

A.1 Households

Households maximize (6) subject to (7), (9) and (**??**), by choosing $C_t(j)$ $N_t(j)$, $\frac{B_{G,t}(j)}{P_t}$, $\frac{B_{G,L,t}(j)}{P_t}$, $\frac{B_{G,L,n,t}}{P_t}$ and $R_{G,L,t}(j)$.[11] The Lagrangian is given by

$$
\begin{aligned}
&\sum_{i=0}^{\infty}\beta^i\left[\begin{array}{c}
\frac{\left(C(j)_{t+i}-hC_{t+i-1}\right)^{1-\sigma_c}}{1-\sigma_c}exp\left(\frac{\sigma_c-1}{1+\sigma_l}N_{t+i}^{1+\sigma_l}(j)\right)+\\
\frac{\chi_{b,t+i}}{1-\sigma_b}\left(\frac{B_{G,t+i}(j)}{P_{t+i}}+\frac{B_{G,L,t+i}(j)}{P_{t+i}}\right)^{1-\sigma_b}+\\
\frac{\chi_{K,t+i}}{1-\sigma_K}\bar{K}_{t+i}^{1-\sigma_K}(j)+\left(\frac{B_{G,t+i}(j)}{P_{t+i}}+\frac{B_{G,L,t+i}(j)}{P_{t+i}}\right)\chi_{\varepsilon_b,t+i}\varepsilon_{b,t+i}
\end{array}\right]\\
&+\sum_{i=0}^{\infty}\beta^i\Xi_{t+i}\left[\begin{array}{c}
\frac{R_{t+i-1}}{\Pi_{t+i}}\frac{B_{G,t+i-1}}{P_{t+i-1}}(j)+\frac{(R_{L,t+i-1}-1+\omega_{LTD})}{\Pi_{t+i}}\frac{B_{G,L,t+i-1}}{P_{t+i-1}}(j)\\
+\left(1-\tau_{w,h,t+i}-\tau_{L,t+i}\right)\frac{W_{t+i}(j)}{P_{t+i}}N(j)_{t+i}-T_{t+i}+Prof(j)_{t+i}\\
+\left(\left(1-\tau_{K,t+i}\right)\left(r_{K,t+i}Z_{t+i}(j)-a\left(Z_{t+i}(j)\right)\right)+\tau_{K,t+i}\delta\right)\bar{K}_{t+i-1}(j)\\
-\left(\frac{B_{G,t+i}(j)}{P_{t+i}}+\frac{B_{G,L,n,t+i}(j)}{P_{t+i}}+\left(1+\tau_{C,t+i}\right)C_{t+i}(j)+I_t(j)\right)
\end{array}\right]\\
&+\sum_{i=0}^{\infty}\beta^i\Xi_{t+i}\left[\begin{array}{c}
\mu_{RGL,t+i}(j)\left(\begin{array}{c}
\left(1-\omega_{LTD}\right)\frac{(R_{G,L,t+i-1}(j)-1)}{\Pi_{t+i}}\frac{B_{G,L,t+i-1}(j)}{P_{t+i-1}}\\
+\left(R_{G,L,n,t+i}-1\right)\frac{B_{L,n,t+i}(j)}{P_{t+i}}-\left(R_{G,L,t+i}(j)-1\right)\frac{B_{G,L,t+i}(j)}{P_{t+i}}
\end{array}\right)\\
+\mu_{bGL,t+i}(j)\left(\left(1-\omega_{LTD}\right)\frac{\frac{B_{G,L,t+i-1}(j)}{P_{t+i-1}}}{\Pi_{t+i}}+\frac{B_{G,L,n,t+i}(j)}{P_{t+i}}-\frac{B_{G,L,t+i}(j)}{P_{t+i}}\right)
\end{array}\right]\\
&+\sum_{i=0}^{\infty}\beta^i\Xi_{t+i}^k\left[\bar{K}_{t+i}(j)-(1-\delta)\bar{K}_{t+i-1}(j)+\varepsilon_{I,t+i}\left(1-S\left(\frac{I_{t+i}(j)}{I_{t+i-1}(j)}\right)\right)I_{t+i}(j)\right]
\end{aligned}
$$

The first order conditions are given by

[11] The reason that the average interest rate on the households bond portfolio $R_{G,L,t}$ is a choice variable is that it is affected by the households purchases of newly issued bonds $B_{G,L,n,t}$. By contrast, the market interest rate on newly issued bonds $R_{G,L,n,t}$ is taken as given by the household (see Krause and Moyen (2016)).

$$\Xi_t = \beta E_t\left\{\Xi_{t+1}\frac{R_t}{\Pi_{t+1}}\right\} + \chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b} + \chi_{\varepsilon_b,t}\varepsilon_{b,t} \tag{23}$$

$$\Xi_t\left(\mu_{bGL,t}+\mu_{RGL,t}\left(R_{G,L,t}-1\right)\right) = \tag{24}$$

$$\beta\Xi_{t+1}\left[\frac{\left(R_{L,t}-1+\omega_{LTD}\right)+\left(1-\omega_{LTD}\right)\left[\mu_{RGL,t+1}\left(R_{G,L,t}-1\right)+\mu_{bGL,t+1}\right]}{\Pi_{t+1}}\right] \tag{25}$$

$$+\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b} + \chi_{\varepsilon_b,t}\varepsilon_{b,t} \tag{26}$$

$$\mu_{RGL,t} = \beta\Xi_{t+1}\frac{1+\mu_{RGL,t+1}\left(1-\omega_{LTD}\right)}{\Pi_{t+1}} \tag{27}$$

$$\mu_{bGL,t} = 1-\mu_{RGL,t}\left(R_{G,L,n,t}-1\right) \tag{28}$$

Combining (27) and (24) yields

$$\begin{aligned}
&\left(\mu_{bGL,t}+\beta E_t\left\{\frac{\Xi_{t+1}}{\Xi_t}\frac{}{\Pi_{t+1}}\left[1+\mu_{RGL,t+1}\left(1-\omega_{LTD}\right)\right]\right\}\left(R_{G,L,t}-1\right)\right)\\
&=\beta\frac{\Xi_{t+1}}{\Xi_t}\left[\frac{\left(R_{L,t}-1+\omega_{LTD}\right)+\left(1-\omega_{LTD}\right)\left[\mu_{RGL,t+1}\left(R_{G,L,t}-1\right)+\mu_{bGL,t+1}\right]}{\Pi_{t+1}}\right]\\
&+\frac{\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}}{\Xi_t}+\frac{\chi_{\varepsilon_b,t}}{\Xi_t}\varepsilon_{b,t}
\end{aligned}$$

or

$$\begin{aligned}
\mu_{bGL,t} = \beta E_t&\left\{\frac{\Xi_{t+1}}{\Xi_t}\frac{1}{\Pi_{t+1}}\left[\omega_{LTD}+\left(1-\omega_{LTD}\right)\mu_{bGL,t+1}\right]\right\}\\
&+\frac{\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}}{\Xi_t}+\frac{\chi_{\varepsilon_b,t}}{\Xi_t}\varepsilon_{b,t}
\end{aligned} \tag{29}$$

Combining (24) and (28) yields

$$\begin{aligned}
&\Xi_t\left(1-\mu_{RGL,t}\left(R_{G,L,n,t}-1\right)+\mu_{RGL,t}\left(R_{G,L,t}-1\right)\right)=\\
&\beta\Xi_{t+1}\left[\frac{\left(R_{L,t}-1+\omega_{LTD}\right)+\left(1-\omega_{LTD}\right)\left[\mu_{RGL,t+1}\left(R_{G,L,t}-1\right)+1-\mu_{RGL,t+1}\left(R_{G,L,n,t+1}-1\right)\right]}{\Pi_{t+1}}\right]\\
&+\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}+\chi_{\varepsilon_b,t}\varepsilon_{b,t}
\end{aligned}$$

or

$$\Xi_t \left(1-\mu_{RGL,t}\left(R_{G,L,n,t}-R_{G,L,t}\right)\right) =$$
$$\beta \Xi_{t+1}\left[\frac{\left(R_{L,t}-1+\omega_{LTD}\right)+\left(1-\omega_{LTD}\right)\left[1-\mu_{RGL,t+1}\left(R_{G,L,n,t+1}-R_{G,L,t}\right)\right]}{\Pi_{t+1}}\right]$$
$$+\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}+\chi_{\varepsilon_b,t}\varepsilon_{b,t}$$

or

$$\Xi_t \left(1-\mu_{RGL,t}\left(R_{G,L,n,t}-R_{G,L,t}\right)\right) = \beta \Xi_{t+1}\left[\frac{\left(R_{L,t}\right)-\left(1-\omega_{LTD}\right)\mu_{RGL,t+1}\left(R_{G,L,n,t+1}-R_{G,L,t}\right)}{\Pi_{t+1}}\right]$$
$$+\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}+\chi_{\varepsilon_b,t}\varepsilon_{b,t}$$

Substituting (27) yields

$$\Xi_t \left(1-\beta \Xi_{t+1}\frac{1+\mu_{RGL,t+1}\left(1-\omega_{LTD}\right)}{\Pi_{t+1}}\left(R_{G,L,n,t}-R_{G,L,t}\right)\right) =$$
$$\beta \Xi_{t+1}\left[\frac{\left(R_{L,t}\right)-\left(1-\omega_{LTD}\right)\mu_{RGL,t+1}\left(R_{G,L,n,t+1}-R_{G,L,t}\right)}{\Pi_{t+1}}\right]$$
$$+\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}+\chi_{\varepsilon_b,t}\varepsilon_{b,t}$$

or

$$\Xi_t \left(1-\beta \Xi_{t+1}\frac{1+\mu_{RGL,t+1}\left(1-\omega_{LTD}\right)}{\Pi_{t+1}}\left(R_{G,L,n,t}\right)\right) =$$
$$\beta \Xi_{t+1}\left[\frac{-\left(1-\omega_{LTD}\right)\mu_{RGL,t+1}R_{G,L,n,t+1}}{\Pi_{t+1}}\right]$$
$$+\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}+\chi_{\varepsilon_b,t}\varepsilon_{b,t}$$

or

$$\Xi_t = \beta \Xi_{t+1}\left[\frac{R_{G,L,n,t}+\mu_{RGL,t+1}\left(1-\omega_{LTD}\right)R_{G,L,n,t}-\left(1-\omega_{LTD}\right)\mu_{RGL,t+1}R_{G,L,n,t+1}}{\Pi_{t+1}}\right]$$
$$+\chi_{b,t}\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}+\chi_{\varepsilon_b,t}\varepsilon_{b,t}$$

or

$$\Xi_t = \beta E_t \left\{ \Xi_{t+1} \frac{R_{L,n,t} - \mu_{RGL,t+1}\left(1-\omega_{LTD}\right)\left(R_{L,n,t+1} - R_{L,n,t}\right)}{\Pi_{t+1}} \right\} \tag{30}$$

$$+ \chi_{b,t}\left(\frac{B_{G,t}}{P_t} + \frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b} + \chi_{\varepsilon_b,t}\varepsilon_{b,t}$$

$$\mu_{RGL,t} = \beta E_t \left\{ \frac{\Xi_{t+1}}{\Xi_t}\frac{1}{\Pi_{t+1}}\left[1 + \mu_{RGL,t+1}\left(1-\omega_{LTD}\right)\right] \right\} \tag{31}$$

where $\mu_{RGL,t}$ and $\mu_{bGL,t}$ denotes the Lagrange multipliers on the law of motion of the average interest rate (**??**) and total long-term government bonds (41), respectively. These equations are identical to Krause and Moyen except for the term reflecting the marginal utility of government bonds $\chi_{b,t}\left(\frac{B_{G,t}}{P_t} + \frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b}$ in equations (23) and (30).

The other first order conditions are standard:

$$\Xi_t^k = \beta E_t \left[\Xi_{t+1}\left(\left(1-\tau_{K,t+1}\right)\left(r_{K,t+1}Z_{t+1} - a(Z_{t+1})\right) + \tau_{K,t+1}\delta\right) + \Xi_{t+1}^k\left(1-\delta\right)\right]$$

$$+ \chi_{K,t}\bar{K}_t^{-\sigma_K} \iff$$

$$Q_t = \beta E_t \left[\frac{\Xi_{t+1}}{\Xi_t}\left(\left(1-\tau_{K,t+1}\right)\left(r_{K,t+1}Z_{t+1} - a(Z_{t+1})\right) + \tau_{K,t+1}\delta + \left(1-\delta\right)Q_{t+1}\right)\right]$$

$$+ \frac{\chi_{K,t}\bar{K}_t^{-\sigma_K}}{\Xi_t}$$

$$r_{K,t} = a'\left(Z_t\right)$$

$$\Xi_t\left(1+\tau_{C,t}\right) = \left(C\left(j\right)_{t+i} - hC_{t+i-1}\right)^{-\sigma_c} exp\left(\frac{\sigma_c - 1}{1+\sigma_\ell}L_t^{1+\sigma_\ell}\left(\hbar\right)\right)$$

$$\Xi_t\frac{\left(1-\tau_{w,h,t} - \tau_{L,t}\right)W_{t+j}\left(j\right)}{P_{t+j}} = \left(\tfrac{1}{1-\sigma_c}\left(C\left(j\right)_{t+i} - hC_{t+i-1}\right)^{1-\sigma_c}\right)\cdot \exp\left(\tfrac{\sigma_c-1}{1+\sigma_\ell}L_t\left(\hbar\right)^{1+\sigma_\ell}\right)\ \left(\sigma_c - 1\right)L_t^{\sigma_l}\left(\hbar\right)$$

$$\Xi_t = \Xi_t^k\varepsilon_{I,t}\left(1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right)$$

$$+ \beta E_t\left[\Xi_{t+1}^k\varepsilon_{I,t+1}S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right]$$

A.2 Firm Cost minimization

Production function:

$$Y_t = A_t\left(TFP_tL_t\right)^{1-\alpha}K_t^\alpha - TFP_t\Phi$$

$$\frac{W_t}{P_t}\left(1+\tau_{w,f,t}\right) = mc_t\left(1-\alpha\right)\frac{Y_t+TFP_t\Phi}{L_t} \tag{32}$$

$$r_{K,t} = mc_t\alpha\frac{Y_t+TFP_t\Phi}{K_t} \tag{33}$$

where TFP_t denotes the technology trend (grows deterministically) in SW, with

$$\gamma_t = \frac{TFP_t}{TFP_{t-1}} \tag{34}$$

A.3 Detrending

Detrending using $\Xi_t = \frac{\xi_t}{TFP_t^{\sigma_c}}$, and assuming $\chi_{b,t} = \frac{TFP_t^{-\sigma_c}}{TFP_t^{-\sigma_b}}\chi_b$ and $\chi_{K,t} = \frac{TFP_t^{-\sigma_c}}{TFP_t^{-\sigma_K}}\chi_K$ and $\chi_{\varepsilon_b,t} = \frac{\chi_\epsilon}{TFP_t^{\sigma_c}}$

$$\begin{aligned}
\frac{\xi_t}{TFP_t^{\sigma_c}} &= \beta E_t\left\{\frac{\xi_{t+1}}{TFP_{t+1}^{\sigma_c}}\frac{R_t}{\Pi_{t+1}}\right\} + \frac{TFP_t^{-\sigma_c}}{TFP_t^{-\sigma_b}}\chi_b\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b} \\
&\quad + \frac{\chi_\epsilon}{TFP_t^{\sigma_c}}\varepsilon_{b,t} \\
\frac{\xi_t}{TFP_t^{\sigma_c}} &= \beta E_t\left\{\frac{\xi_{t+1}}{TFP_{t+1}^{\sigma_c}}\frac{R_{L,n,t}-\mu_{RGL,t+1}\left(1-\omega_{LTD}\right)\left(R_{L,n,t+1}-R_{L,n,t}\right)}{\Pi_{t+1}}\right\} \\
&\quad + \frac{TFP_t^{-\sigma_c}}{TFP_t^{-\sigma_b}}\chi_b\left(\frac{B_{G,t}}{P_t}+\frac{B_{G,L,t}}{P_t}\right)^{-\sigma_b} + \frac{\chi_\epsilon}{TFP_t^{\sigma_c}}\varepsilon_{b,t} \\
\mu_{RGL,t} &= \beta E_t\left\{\frac{\frac{\xi_{t+1}}{TFP_{t+1}^{\sigma_c}}}{\frac{\xi_t}{TFP_t^{\sigma_c}}}\frac{1}{\Pi_{t+1}}\left[1+\mu_{RGL,t+1}\left(1-\omega_{LTD}\right)\right]\right\} \\
Q_t &= \beta E_t\left[\frac{\frac{\xi_{t+1}}{TFP_{t+1}^{\sigma_c}}}{\frac{\xi_t}{TFP_t^{\sigma_c}}}\left(r_{K,t+1}-a(Z_{t+1})+\left(1-\delta\right)Q_{t+1}\right)\right] + \frac{\frac{TFP_t^{-\sigma_c}}{TFP_t^{-\sigma_K}}\chi_K\bar{K}_t^{-\sigma_K}}{\frac{\xi_t}{TFP_t^{\sigma_c}}} \\
\left(1+\tau_{C,t}\right)\xi_t &= \left(c_{O,t}-\frac{h}{\gamma}.c_{O,t-1}\right)^{-\sigma_c} exp\left(\frac{\sigma_c-1}{1+\sigma_\ell}N_t^{1+\sigma_\ell}\right) \\
\xi_t\left(1-\tau_{w,h,t}-\tau_{N,t}\right)w_{h,t} &= \left(\left(c_{O,t}-\frac{h}{\gamma}.c_{O,t-1}\right)^{1-\sigma_c}\right) exp\left(\frac{\sigma_c-1}{1+\sigma_\ell}N_t^{1+\sigma_\ell}\right)\ N_t^{\sigma_l} \\
1 &= Q_t\varepsilon_{I,t}\left(1-S\left(\frac{I_tTFP_{t-1}}{I_{t-1}TFP_t}\frac{TFP_t}{TFP_{t-1}}\right)-S'\left(\frac{I_tTFP_{t-1}}{I_{t-1}TFP_t}\frac{TFP_t}{TFP_{t-1}}\right)\frac{I_tTFP_{t-1}}{I_{t-1}TFP_t}\frac{TFP_t}{TFP_{t-1}}\right) \\
&\quad + \beta E_t\left[\frac{\frac{\xi_{t+1}}{TFP_{t+1}^{\sigma_c}}}{\frac{\xi_t}{TFP_t^{\sigma_c}}}Q_{t+1}A_{I,t}\varepsilon_{I,t+1}S'\left(\frac{I_{t+1}TFP_t}{I_tTFP_{t+1}}\frac{TFP_{t+1}}{TFP_t}\right)\left(\frac{I_{t+1}TFP_t}{I_tTFP_{t+1}}\frac{TFP_{t+1}}{TFP_t}\right)^2\right]
\end{aligned}$$

Or

$$\xi_t = \beta E_t \left\{ \frac{\xi_{t+1}}{\gamma_{t+1}^{\sigma_c}} \frac{R_t}{\Pi_{t+1}} \right\} + \chi_b \left(b_{G,t} + b_{G,L,t}\right)^{-\sigma_b} + \chi_\epsilon \varepsilon_{b,t} \tag{35}$$

$$\xi_t = \beta E_t \left\{ \frac{\xi_{t+1}}{\gamma_{t+1}^{\sigma_c}} \frac{R_{L,n,t} - \mu_{RGL,t+1}\left(1-\omega_{LTD}\right)\left(R_{L,n,t+1} - R_{L,n,t}\right)}{\Pi_{t+1}} \right\} + \chi_b \left(b_{G,t} + b_{G,L,t}\right)^{-\sigma_b} + \chi_\epsilon \varepsilon_{b,t} \tag{36}$$

$$\mu_{RGL,t} = \beta E_t \left\{ \frac{1}{\Pi_{t+1}} \frac{\xi_{t+1}}{\gamma_{t+1}^{\sigma_c}\xi_t} \left[1 + \mu_{RGL,t+1}\left(1-\omega_{LTD}\right)\right] \right\} \tag{37}$$

$$= \beta E_t \left\{ \frac{\xi_{t+1}}{\gamma_{t+1}^{\sigma_c}\xi_t} \frac{1}{\Pi_{t+1}} \left[\omega_{LTD} + \left(1-\omega_{LTD}\right) Q_{b,G,L,t+1}\right] \right\} + \frac{\chi_b \left(b_{G,t} + b_{G,L,t}\right)^{-\sigma_b}}{\xi_t} + \frac{1}{\xi_t}\chi_\epsilon \varepsilon_{b,t} \tag{38}$$

$$Q_t = \beta E_t \left[\frac{\xi_{t+1}}{\gamma_{t+1}^{\sigma_c}\xi_t} \left(\left(1-\tau_{K,t+1}\right)\left(r_{K,t+1}Z_{t+1} - a(Z_{t+1})\right) + \tau_{K,t+1}\delta + \left(1-\delta\right)Q_{t+1}\right) \right] + \frac{\chi_K \bar{k}_t^{-\sigma_K}}{\xi_t} \tag{39}$$

$$1 = Q_t \varepsilon_{I,t} \left(1 - S\left(\frac{i_t\gamma_t}{i_{t-1}}\right) - S'\left(\frac{i_t}{i_{t-1}\gamma_t}\right)\frac{i_t\gamma_t}{i_{t-1}} \right) + \beta E_t \left[\frac{\xi_{t+1}}{\xi_t\gamma_{t+1}^{\sigma_c}} Q_{t+1} A_{I,t} \varepsilon_{I,t+1} S'\left(\frac{i_{t+1}}{i_t}\gamma_{t+1}\right)\left(\frac{i_{t+1}}{i_t}\gamma_{t+1}\right)^2 \right] \tag{40}$$

From (9)

$$\frac{B_{G,L,t}}{TFP_tP_t} = \left(1-\omega_{LTD}\right) \frac{\frac{B_{G,L,t-1}}{P_{t-1}TFP_t}\frac{TFP_{t-1}}{TFP_{t-1}}}{\Pi_t} + \frac{B_{G,L,n,t}}{TFP_tP_t}$$

or

$$b_{G,L,t} = \left(1-\omega_{LTD}\right)\frac{b_{G,L,t-1}}{\Pi_t\gamma_t} + b_{G,L,n,t} \tag{41}$$

From (**??**)

$$\left(R_{G,L,t}-1\right)\frac{B_{G,L,t}}{TFP_tP_t} = \left(1-\omega_{LTD}\right)\frac{\left(R_{G,L,t-1}-1\right)}{\Pi_t}\frac{B_{G,L,t-1}TFP_{t-1}}{TFP_tP_{t-1}TFP_{t-1}} + \left(R_{G,L,n,t}-1\right)\frac{B_{L,n,t}}{P_tTFP_t}$$

or

$$\left(R_{G,L,t}-1\right)b_{G,L,t} = \left(1-\omega_{LTD}\right)\frac{\left(R_{G,L,t-1}-1\right)}{\Pi_t}\frac{b_{G,L,t-1}}{\gamma_t} + \left(R_{G,L,n,t}-1\right)b_{L,n,t} \tag{42}$$

Combining (41) and (42) yields

$$\left(R_{G,L,t}-1\right)b_{G,L,t}=\left(1-\omega_{LTD}\right)\frac{\left(R_{G,L,t-1}-1\right)}{\Pi_t}\frac{b_{G,L,t-1}}{\gamma_t}+\left(R_{G,L,n,t}-1\right)\left(b_{G,L,t}-\left(1-\omega_{LTD}\right)\frac{b_{G,L,t-1}}{\Pi_t\gamma_t}\right)$$

or

$$\left(R_{L,t}-R_{L,n,t}\right)b_{G,L,t}=\left(1-\omega_{LTD}\right)\frac{\left(R_{L,t-1}-R_{L,n,t}\right)}{\Pi_t\gamma_t}b_{G,L,t-1} \tag{43}$$

From (**??**)

$$\frac{B_{G,L,t}}{P_t}=\frac{R_{G,L,t-1}}{\Pi_t}\frac{B_{G,L,t-1}}{P_{t-1}}+G_t-\left(T_t+\left(\tau_{w,h,t}+\tau_{w,f,t}\right)w_tN_t+\tau_CC_t+\tau_{K,t}Prof_t\right) \tag{44}$$

$$\frac{B_{G,L,t}}{TFP_tP_t}=\frac{R_{G,L,t-1}}{\Pi_t}\frac{B_{G,L,t-1}}{TFP_tP_{t-1}}+\frac{G_t}{TFP_t}-\left(\frac{T_t}{TFP_t}+\left(\tau_{w,h,t}+\tau_{w,f,t}\right)\frac{W_t}{TFP_tP_t}L_t+\tau_C\frac{C_t}{TFP_t}+\tau_{K,t}\frac{Prof_t}{TFP_t}\right)$$

or

$$\frac{B_{G,L,t}}{TFP_tP_t}=\frac{R_{G,L,t-1}}{\Pi_t}\frac{TFP_{t-1}B_{G,L,t-1}}{TFP_tTFP_{t-1}P_{t-1}}+\frac{G_t}{TFP_t}-\left(t_t+\left(\tau_{w,h,t}+\tau_{w,f,t}\right)\frac{W_t}{TFP_tP_t}L_t+\tau_C\frac{C_t}{TFP_t}+\tau_{K,t}\frac{Prof_t}{TFP_t}\right)$$

$$b_{G,t}=\frac{R_{L,t-1}}{\Pi_t\gamma_t}b_{G,t-1}+g_t-\left(t_t+\left(\tau_{w,h,t}+\tau_{w,f,t}\right)w_tN_t+\tau_{C,t}l_t+\tau_{K,t}prof_t\right) \tag{45}$$

$$\frac{NProf_t}{TFP_t}=\frac{Y_t}{TFP_t}-\left(1+\tau_{w,f,t}\right)\frac{\frac{W_t}{P_t}}{TFP_t}N_t-\left(\delta+a\left(Z_t\right)\right)\frac{\bar{K}_{t-1}}{TFP_t}=$$

$$y_t-\left(1+\tau_{w,f,t}\right)w_tN_t-\left(\delta+a\left(Z_t\right)\right)\frac{\bar{K}_{t-1}}{TFP_{t-1}}\frac{TFP_{t-1}}{TFP_t} \tag{46}$$

$$nprof_t=y_t-\left(1+\tau_{w,f,t}\right)w_tN_t-\left(\delta+a\left(Z_t\right)\right)\frac{\bar{k}_{t-1}}{\gamma_t} \tag{47}$$

Primary deficit ratio:

$$PDY_t=\frac{\left(g_t-\left(t_t+\left(\tau_{w,h,t}+\tau_{w,f,t}\right)w_tN_t+\tau_Cl_t+\tau_{K,t}\left(r_{K,t}-\delta\right)k_t\right)\right)}{y_t} \tag{48}$$

Debt-to-annualized GDP ratio

$$b2gdp_t=\frac{b_{G,t}}{4Y_t}$$

Production function

$$y_t = A_t (N_t)^{1-\alpha} k_t^{\alpha} - \Phi$$

Firm FOCs

$$w_t (1 + \tau_{w,f,t}) = mc_t (1 - \alpha) \frac{y_t + \Phi}{N_t} \tag{49}$$

Capital accumulation: From

$$\begin{aligned}
\frac{\bar{K}_t}{TFP_t} &= (1 - \delta) \frac{\bar{K}_{t-1}}{TFP_t} + \frac{I_t}{TFP_t} \Leftrightarrow \\
\bar{k}_t &= (1 - \delta) \frac{TFP_{t-1}}{TFP_t} \frac{\bar{K}_{t-1}}{TFP_{t-1}} + i_t \Leftrightarrow \\
\bar{k}_t &= (1 - \delta) \frac{\bar{k}_{t-1}}{\gamma_t} + i_t
\end{aligned} \tag{50}$$

$$\begin{aligned}
\frac{K_t}{TFP_t} &= \frac{\bar{K}_{t-1}}{TFP_t} Z_t \Leftrightarrow \\
k_t &= \frac{\bar{K}_{t-1}}{TFP_{t-1}} \frac{TFP_{t-1}}{TFP_t} Z_t = \frac{\bar{k}_{t-1}}{\gamma_t} Z_t
\end{aligned} \tag{51}$$

A.4 Resource constraint

$$y_t = c_t + i_t + g_t + x_t \tag{52}$$

B Data used in the estimation and calibration

Unless otherwise mentioned, we obtained all fiscal data referred to below from the Euro Area fiscal database of Paredes et al. (2014) and all remaining macroeconomic data from the Area Wide Model database of Fagan et al. (2005).

B.1 Macroeconomic data

- I computed GDP_t, $CONS_t$, $INVE_t$ and GOV_t as $\frac{X_t}{POP_t * \frac{YED_t}{100}}$, where
  - X_t : Respective nominal data:
    - $NGDP_t = YER_t * YED_t$
    - $NCONS_t = CER_t * CED_t$

    * $NINVE_t = ITR_t * ITD_t - GIN_t$, where GIN_t denotes government investment from the Euro Area fiscal database.
  - POP_t : Working age population.
  - YED_t: GDP deflator.

- $WREAL_t = \frac{\frac{WIN_t}{LNN_t}}{YED_t}$, where WIN_t denotes compensation of employees and LNN_t denotes total employment.

- $\widehat{LNN}_t$: Detrended employment (heads). This is series is constructed by first decomposing the log of employment $ln\left(LNN_t\right)$ into $ln\left(LNN_t\right) = ln\left(\frac{LNN_t}{LFN_t}\right) + ln\left(\frac{LFN_t}{POP_t}\right)$, where LFN_t denotes the labor force (implying that $1 - \frac{LNN_t}{LFN_t}$ yields the unemployment rate), and then, stationarize them separately, similar to Campbell et al. (2019). $ln\left(\frac{LNN_t}{LFN_t}\right)$ doesn't display an obvious time trend over the sample, and using Dickey-Fuller test where the alternative hypothesis is a stationary process without a time trend, we can reject the unit root hypothesis with 98% confidence over the sample period. Therefore we only demean it. By contrast, $ln\left(\frac{LFN_t}{POP_t}\right)$ displays a trend (though no unit root), therefore we remove a linear trend. with the detrended hours series of Campbell et al. (2019) .

- STI_t: Short term interest rate (or policy rate). See B.3.

- $CPI6to10_t$: Average inflation expected for the 6th to the 10th year from today. Obtained from
  - 2005Q2-2019Q4: Expectations component of inflation linked swap rates, estimated by Camba-MÃ©ndez and Werner (2017).
  - 1990Q2-2005Q1: Average inflation expected for the 6th to 10th calendar year from today from Consensus Economics, collected by Stevens and Wauters (2018). The pre-1999 data is a GDP weighted average of the respective country values of France, Germany, Italy, Netherlands and Spain.

B.2 Fiscal data

- PY_t: Deficit-to-GDP ratio, constructed as $PDY_t = \frac{DEF_t}{YER_t * YED_t} * 100$, where DEF_t denotes the headline government deficit. DEF_t differs from Paredes et al. (2014) in that, when calculating total government expenditures, we replace the nominal government consumption series in the fiscal database with the corresponding series from the Area Wide Model database, i.e. $GCD_t * GCR_t$.

- GGY_t: Government-demand-to-GDP ratio, constructed as $GGY_t = \frac{GG_t}{YER_t * YED_t} * 100$, with $GG_t = GCD_t * GCR_t + GIN_t$, where GIN_t denotes government investment from the Euro Area fiscal database.

- $DTXY_t$: Share of direct tax revenue in GDP, constructed as $DTXY_t = \frac{DTX_t}{YER_t * YED_t} * 100$, where DTX_t denotes "EA general government total direct taxes".

- $SCRY_t$: Share employer social security contributions in GDP, constructed as $SCRY_t = \frac{SCR_t}{YER_t * YED_t} * 100$, where SCR_t denotes "EA general gov. social security contributions by employers".

- $SCEY_t$: Share employee social security contributions in GDP, constructed as $SCEY_t = \frac{SCE_t}{YER_t * YED_t} * 100$, where SCE_t denotes "EA general gov. social security contributions by employees, self-employed and other".

- $TAUC_t$: Implicit consumption tax rate, constructed as $TAUC_t = \frac{TIN_t}{CER_t * CED_t} * 100$, where TIN_t denotes "EA general government total indirect taxes".

- Government-Debt-to-GDP ratio$= \frac{MAL_t}{YER_t * YED_t} * 100$, where MAL_t denotes Euro area general government debt.

- Average maturity of outstanding government debt: Calculated as a government-debt-weighted average of the respective values of Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal and Spain. For 1992-2010, I obtained the country specific average maturities from the OECD database ("Average term to maturity for total debt, Central government"). Since the series ends in 2010, I obtained the values for the 2011-2018 period from the 2011-2018 annual issues of the IMF Fiscal Monitor. I used "General government consolidated gross debt :- Excessive deficit procedure (based on ESA 2010) and former definition (linked series)" from the European Commission's database AMECO to calculate the country weights.

B.3 Short term interest rate (STI_t) and interest rate expectations ($STIEX_{i,t}$)

We obtained my measure of interest rate expectations $STIEX_{i,t}$ and and the short term interest rate or policy rate STI_t as described below.

- 1999Q1-2019Q4:
  - STI_t : EONIA quarterly average, from the ECB's Statistical Data Warehouse (ECB-SDW)

- $STIEX_{i,t}$: OIS rates, available for $i = 1 - 8$ and $i = 12$, from Bloomberg. Exception: 1999Q1-2004Q4, where I also use Bund Zero Coupon Yields (ZCY) during some quarters (obtained from Deutsche Bundesbank), since the OIS curve does not always extend beyond a horizon of $i = 4$ or $i = 8$. During the 1999-2009 period, the Bund ZCY differ only marginally from OIS rates of the same maturity.
  - 1999Q1-2000Q4: $i = 8$: 2 year Bund ZCY.
  - 1999Q1-2004Q4: $i = 12$: 3 year Bund ZCY.
- The OIS data are averages over the final five days of the quarter. The Bund ZCY is from the final day of quarter, as the original data are end-of-month values.

- 1994Q1-1998Q4:
  - STI_t: 3-month Euribor, average over the first month of the quarter, from ECBSDW.
  - $STIEX_{i,t}, i = 1, 2, 4$: 3, 6 and 12 month Euribor, average over the final month of the quarter, from ECBSDW.
  - $STIEX_{i,t}, i = 8, 12$: $STIEX_{i,t} = ZCY_{i,t} + (STIEX_{4,t} - ZCY_{4,t})$ where the $ZCY_{i,t}$ denote the zero coupon yields on a government bond with the corresponding maturity. We calculated the $ZCY_{i,t}$ as GDP-weighted averages of the values of Belgium, Germany, France, Spain and Italy, obtained from the BIS Databank. The country specific values are averages over the final month of the quarter.

- 1990Q1-1993Q4:
  - STI_t :GDP weighted average of 3-month money market rates of Austria, Spain, Germany, France, Netherlands and Italy, average over first month of the quarter. This rate is essentially identical to the Euribor 3 month rate during the period where both are available (i.e. starting 1994Q1).
  - $STIEX_{1,t}$ same source as as STI_t, but average over final month of the quarter.
  - $STIEX_{i,t}$,$i = 2, 4$: Constructed as $STIEX_{i,t} = EM_{i,t} + (EM_{1,t} - STIEX_{1,t})$, with $EM_{1,t}$, $EM_{2,t}$ and $EM_{4,t}$ corresponding to Euro Area 3, 6 and 12 month Euro Market rates, obtained from the BIS Databank. We calculated $EM_{i,t}$ as GDP-weighted averages of the country specific rates of Austria, Belgium, Germany, Spain, France, Italy and the Netherlands. The resulting $STIEX_{i,t}$ series are very close to the Euribor series of the same maturity during the period where both are available (i.e. starting 1994Q1).
  - From 1992Q1: $STIEX_{i,t}, i = 8, 12$: $STIEX_{i,t} = ZCY_{i,t} + (STIEX_{4,t} - ZCY_{4,t})$, where $ZCY_{i,t}$ is as defined above.
  - 1980Q1-1989Q4: $STI_t = STN_t$, the short term interest rate from the AWM database.

- Whenever for a given quarter t, observations for some some intra-annual horizons i are missing, we linearly interpolate them using the values of for two most adjacent horizons available. For instance, for $i = 9 - 11$ we have $STIEX_{i,t} = STIEX_{8,t} + \frac{i-8}{4}\,(STIEX_{12,t} - STIEX_{8,t})$.
- Throughout, GDP weights are computed from 1995 PPS GDP (consistent with the weights of the AWM database), obtained from AMECO.