Non-standard monetary policy measures in the New Normal

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Abstract

We evaluate the macroeconomic effects of long-term sovereign bond purchases by the central bank in the "New Normal," i.e., in an economy characterized by a low equilibrium real interest rate and a high probability of hitting the zero lower bound (ZLB) on short-term policy rate. Our analysis is based on simulations of a dynamic general equilibrium model of the euro area with a banking sector and segmented financial markets. The main results are the following ones. First, long-term sovereign bond purchases reacting to the positive inflation gap help stabilize macroeconomic conditions when the short-term monetary policy rate hits the ZLB, provided they are sufficiently sizable and persistent. Second, purchases are an effective stabilization tool after positive shocks to the sovereign term premium (a financial shock) and negative shocks to aggregate demand (real shocks). Third, purchases reacting also to the long-term rates are effective in the case of recessionary financial shocks but not in the case of recessionary real shocks. Fourth, to stabilize the effects of expansionary shocks, the central bank can react by increasing the short-term monetary policy rate, according to an "aggressive" Taylor rule, instead of selling long-term sovereign bonds.

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1 Introduction

Following prolonged and deep recessionary shocks affecting the euro area (EA) economy, the European Central Bank (ECB) cut the policy rate and then, as the policy rate approached zero, deployed the "non-standard" monetary policy measures. Large-scale purchases of sovereign bonds (public sector purchase programme, PSPP) were among them. Purchases intended to lower long-term interest rates by (directly) reducing term premia between short-term and long-term rates and, thus, to favor the restoring of normal price dynamics conditions. As a by-product, the ECB's balance sheet widely expanded.[1]

To the extent that, in the future, the natural interest rates will remain persistently low (the so-called "New Normal"), the zero lower bound (ZLB) on the (short-term) monetary policy rate may be binding with a non-negligible probability. Thus, policy makers and academics are debating if non-standard policies should become standard, i.e., they should be used on a regular basis to offset recessions or disinflation episodes and, in particular, if the central bank balance sheet management should be part of the standard monetary policy toolkit.

This paper evaluates, for the EA economy, the effects of the central bank using its balance sheet, specifically long-term sovereign bonds purchases and sales, to stabilize macroeconomic conditions in the New Normal. To this purpose, we simulate a New Keynesian dynamic general equilibrium model of the EA. The EA is split in two regions, Home and rest of the EA (REA). The monetary union dimension allows us to take into account possible cross-region asymmetries in the transmission of both the shocks and the policy measures. There is a third region, the rest of the world (RW) that allows us to fully describe trade (intra- and extra-EA) relationships.

The model has the following key features.

First, the central bank, when intervening in the long-term sovereign bond market by buying or selling bonds, follows a systematic feedback rule (we label it as "reaction function") that links bond purchases to the inflation gap, i.e., the difference between the inflation target and the actual inflation rate. Consistent with possible institutional and scarcity constraints, it is assumed that an upper bound can limit the stock of sovereign bond purchases by the EA central bank.

[1]Similar non-standard measures were implemented also in other main industrialized countries. See Dell'Ariccia et al. (2018) for a survey.

Second, in each EA region there is a banking sector that invests in domestic long-term sovereign bonds and intermediates funds between domestic "unrestricted" households (the "savers") on the one hand and domestic "entrepreneurs" and "borrowers" on the other. Savers have access to multiple financial markets. Entrepreneurs own "capital producers" joint with the restricted households. They also rent real estate to domestic firms. Borrowers are another type of households. Both borrowers and entrepreneurs use real estate as collateral when borrowing from the banking sector.[2]

Third, it is assumed that financial markets are segmented, as in Chen et al. (2012). Some households, labeled as "restricted," have a preference for holding long-term sovereign bonds and investing in physical capital (they do not invest in other types of available assets). Market segmentation implies that the perfect substitutability among different financial assets breaks down. The central bank, by purchasing long-term sovereign bonds, directly raises bond prices and reduces their yields. Restricted households sell government bonds to the central bank, rebalancing their portfolios towards investment in physical capital. Thus, the long-term sovereign bonds are issued by the EA regional fiscal authorities, held by the local households and the banking sector and, because of the PSPP implemented in the past and the current systematic purchases, by the central bank.

We feed the model with shocks that drive the EA short-term policy rate to the ZLB: shocks to the term premium between short- and long-term sovereign bonds (financial shocks) and, alternatively, to aggregate demand. Given these ZLB-scenarios, we (alternatively) assume that the central bank follows or does not follow the reaction function described above (if the central bank does not follow it, then purchases are zero). We also run the same simulations under the assumptions that the central bank purchases react not only to the inflation gap but also the long-term interest rates, to investigate its properties.

Our results are the following ones. First, long-term sovereign bond purchases reacting to the positive inflation gap help stabilize macroeconomic conditions when the short-term monetary policy rate hits the ZLB, provided they are sufficiently sizable and persistent. Second, purchases are an effective stabilization tool after positive shocks to the sovereign term premium (a financial

[2] Different from Gerali et al. (2010) and Guerrieri et al. (2013), we include long-term sovereign bonds in the balance sheet of the banks.

shock) and negative shocks to aggregate demand (business cycle shocks). Third, purchases reacting also to the long-term rates are effective in the case of recessionary financial shocks but not in the case of recessionary real shocks. Fourth, to stabilize the effects of expansionary shocks, the central bank can react by increasing the short-term monetary policy rate, according to an "aggressive" Taylor rule, instead of selling long-term sovereign bonds.

This paper contributes to the literature on standard and non-standard monetary policy in the New Normal. Quint and Rabanal (2017) estimate and simulate a DSGE model of the US economy. They find that non-standard measures (asset purchases), that systematically react to credit spreads, are mostly useful to react to financial shocks. They also find that non-standard measures are not particularly effective in stabilizing macroeconomic conditions in correspondence of normal business cycle supply and demand shocks (i.e., real shocks). Harrison (2017) analyzes the efficacy of quantitative-easing strategies in a small New-Keynesian model calibrated to match behavior of the US economy. Similarly, Carlstrom et al. (2017) find non-standard measures useful to counteract financial shocks in a New Keynesian model enriched with a banking sector and financial market segmentation. Ellison and Tischbirek (2014) also build on a framework similar to the one in Chen et al. (2012). They find that central banks should coordinate conventional policy and systematic non-standard measures and, specifically, that the former should respond to inflation while the latter should offset output. Different from these contributions, we introduce the case of monetary policy rate stuck at the ZLB in the analysis. Moreover, we calibrate the model to the EA economy. Burlon et al. (2019) evaluate the role of a temporary feedback rule linking long-term sovereign bond purchases and inflation gap in the EA. Different from that contribution, the reaction function is permanently active and we include a banking sector in the model, in line with the contributions above mentioned (that, as said, neither focus on the EA nor consider the ZLB constraint). Our framework builds on Chen et al. (2012). They assume that bonds with different maturities are imperfect substitutes. In their model some households have a preference for saving with long-term instruments. Different from them, our model features not only households but also banks within a monetary union framework, allowing us to evaluate the role of the region-specific banking sectors for the transmission of the union-wide monetary non-standard policy measures.

The paper is organized as follows. Section 2 illustrates the main features of the model setup and the calibration. Section 3 describes the simulated scenarios and reports the results. Finally, Section 4 concludes.

2 The model

In what follows we provide an overview of the model and describe its crucial features and the calibration of the parameters.

2.1 Overview

The model represents the world economy composed of three regions: Home, REA (the EA is made up of Home and REA), and RW. The size of the world economy is normalized to 1. Home, REA, and RW have sizes equal to n, n^*, and $(1 - n - n^*)$, respectively (with $n > 0$, $n^* > 0$, and $n + n^* < 1$).[3]

Home and REA share the currency and the central bank. The latter, when it is not constrained by the ZLB, sets the nominal interest rate, which reacts to EA-wide inflation and output according to a Taylor rule. The presence of the RW outside the EA allows us to assess the role of the nominal exchange rate and extra-EA trade for the transmission of the sovereign bond purchases by the central bank.

One crucial feature of the model is that the ZLB is an endogenous constraint on the EA (short-term) monetary policy rate and that the central bank follows a reaction function, which dictates to purchase (or sell) domestic long-term sovereign bonds in each EA region according to the size of the positive (negative) EA-wide inflation gap (i.e., the difference between inflation target and actual inflation).

The model structure closely follows Bartocci et al. (2017). Specifically, financial segmentation as in Chen et al. (2012) allows central bank asset purchases to have real effects in our model. Fig. 1 illustrates the core financial structure of the model. In each EA region there are three types of households, labeled “restricted,” “savers,” and “borrowers.”

[3]For each region, size refers to the overall population and to the number of firms operating in each sector.

Restricted households have access only to the domestic long-term sovereign bond market and, joint with domestic non-financial "entrepreneurs" (see below), own shares of domestic "capital producers." The latter are firms that optimally choose investment in physical capital to maximize profits under perfect competition subject to the law of capital accumulation and quadratic adjustment costs on investment, taking prices as given. They rent capital to domestic firms producing intermediate goods and rebate profits to domestic restricted households and entrepreneurs.

Savers have multiple investment choices, because they invest in domestic bank deposits, domestic short- and long-term sovereign bonds, riskless international short-term bonds, traded with savers of other countries, and domestic real estate. Savers hold domestic firms operating in the final and intermediate sectors (other than the capital producers) and the domestic banking sector.

Borrowers obtain loans from the domestic banking sector for consumption purposes after pledging their real estate as collateral.

The banking sector invests in domestic long-term sovereign bonds and lends to domestic borrowers and entrepreneurs. It finances bond purchases and loans through deposits and (bank) capital. The latter is issued as equities to domestic savers.

Entrepreneurs finance their consumption and investment choices by borrowing from domestic banks (their loans are collateralized by the owned real estate). They rent real estate to domestic wholesale firms, that use it as input in the production process.[4] Moreover, they are owners, jointly with restricted households, of domestic capital producers.

All households supply differentiated labor services to domestic non-financial firms (other than capital producers) and act as wage setters in monopolistically competitive labor markets, as they charge a wage markup over their marginal rate of substitution between consumption and leisure.

On the production side, there are (i) firms that, under perfect competition, produce two final goods (consumption and investment goods), (ii) capital producers, and (iii) firms that, under monopolistic competition, produce intermediate tradable and non-tradable goods.

The two final goods are sold domestically and are produced combining all available inter-

[4]Real estate is in fixed aggregate supply in each region. It is exchanged among entrepreneurs, savers, and borrowers. It is a durable non-tradable good that provides utility (housing services) to households.

mediate goods using a constant-elasticity-of-substitution (CES) production function. The two resulting bundles can have different composition.

Intermediate tradable and non-tradable goods are produced combining domestic capital, labor, and real estate. The three productive factors are mobile across the two (tradable and non-tradable) intermediate sectors. Given the assumption of differentiated intermediate goods, firms have market power. Thus, they are price-setter and restrict output to create excess profits. Intermediate tradable goods can be sold domestically and abroad. It is assumed that markets for tradable goods are segmented, so that firms can set a different price in each of the three regions.

In line with other dynamic general equilibrium models of the EA (see, among the others, Warne et al., 2008 and Gomes et al., 2010), we include adjustment costs on real and nominal variables, ensuring that consumption, investment, and prices react in a gradual way to a shock. On the real side, consumption habits and quadratic costs prolong the adjustment of households consumption and investment, respectively. On the nominal side, quadratic costs make wages and prices sticky.[5]

In what follows, we report the equations describing monetary policy in the EA and the main equations for the Home country. Similar equations hold in the REA (we state it when this is not the case). Different from Home and REA, in the RW there is only one (standard) type of household.

2.2 Monetary policy: Taylor rule, ZLB, and reaction function

It is assumed that the ZLB is an endogenous constraint on the EA policy rate, as the EA central bank, in response to a recessionary shock, cannot further reduce the (net) policy rate beyond the ZLB (i.e., the gross policy rate below one). When the ZLB does not hold, the EA central bank sets the policy rate following a standard Taylor rule. Thus, the following equation holds for the EA economy in every period t:

$$\frac{R_t^4}{\overline{R}^4} = max\left\{\frac{1}{\overline{R}^4}, \left(\frac{R_{t-1}^4}{\overline{R}^4}\right)^{\rho_R} \left(\frac{\Pi_{EA,t,t-4}}{\overline{\Pi}_{EA}^4}\right)^{(1-\rho_R)\rho_\pi} \left(\frac{GDP_{EA,t}}{GDP_{EA,t-1}}\right)^{\rho_{GDP}}\right\}, \tag{1}$$

[5] See Rotemberg (1982).

where R is the (gross) quarterly monetary policy rate (thus, R^4 is the annualized interest rate). The parameter ρ_R ($0 < \rho_R < 1$) captures inertia in interest rate setting, while the parameter $\overline{R}$ represents the steady-state gross nominal policy rate. The parameters $\rho_\pi > 0$ and $\rho_{GDP} > 0$ are the weights of EA CPI (gross) yearly inflation rate ($\Pi_{EA,t,t-4} \equiv P_t/P_{t-4}$), taken as a deviation from its steady-state (target) value $\overline{\Pi^4}_{EA}$, and EA GDP growth $\left(\frac{GDP_{EA,t}}{GDP_{EA,t-1}}\right)$, respectively.[6]

Finally, the EA central bank can adopt non-standard monetary policy measures in the form of Home and REA long-term sovereign bonds' purchases, labeled B^L_{CB} and B^{L*}_{CB}, respectively. The central bank intervenes in each regional long-term sovereign bond market and buys (or sells) the local bonds held by the savers, restricted households, and banking sector. The supply of long-term sovereign bonds by the regional government is kept constant across simulations.

Similar to Burlon et al. (2019) we assume the central bank follows a reaction function. The latter dictates that the EA central bank buys local long-term sovereign bonds in each EA region, in proportion to the region-specific GDP, according to the size of the (positive) EA-wide inflation gap (i.e., the difference between inflation target and actual inflation).

Moreover, we adopt a conservative approach: given that scarcity of available bonds to purchase in the markets can be an issue for the EA central bank, when simulating the model we assume that an upper bound can limit the overall (cumulated) amount of central bank purchases.

Thus, in each regional long-term sovereign bond market the EA central bank systematically purchases bonds according to the function

$$B^L_{CB,t} = \overline{B}^L_{CB} + min\left(B^{L,upper}_{CB}, \phi_{CB}\left(\overline{\Pi}_{EA} - \Pi_{EA,t}\right) + \rho_{CB} B^L_{CB,t-1}\right), \tag{2}$$

where $\overline{B}^L_{CB}$ is the amount of bonds held in steady state by the central bank, $B^{L,upper}_{CB}$ is the upper bound on purchases, $\phi_{CB} > 0$ is a parameter regulating the amount of additional central bank purchases corresponding to each percentage-point deviation of current EA quarterly inflation from the central bank target, and $0 \leq \rho_{CB} < 1$ measures inertia in the stock of purchases. Because of the *min* operator, the central bank can buy at most the amount $B^{L,upper}_{CB}$ of bonds. The purchases in each regional market are dictated by the corresponding regional-to-EA GDP

[6] The EA CPI inflation rate is a geometric average of Home and REA CPI inflation rates (respectively $\Pi_{C,t}$ and $\Pi^*_{C,t}$) with weights equal to the correspondent country size. The EA GDP, denoted $GDP_{EA,t}$, is the sum of Home and REA GDP.

(steady-state) share.

The above function links asset purchases to the EA inflation gap and is perfectly known by agents.[7]

2.3 Households

In each EA region there are three types of households: savers, borrowers, and restricted households. Specifically, there is a continuum of households of different types. Each of them have a specific mass: $0 < \lambda_{sav}, \lambda_{bor}, \lambda_{res} < 1$ for savers, borrowers, and restricted households, respectively. Their sizes are such that their sum, plus the mass of entrepreneurs $0 < \lambda_{ent} < 1$ (see Section 2.4), is equal to 1, so that the total mass of households and entrepreneurs is equal to the dimension of the country.[8]

2.3.1 Savers

Each saver j maximizes her lifetime expected utility subject to the budget constraint. The lifetime expected utility, in consumption of non-durable goods C_{sav}, labor L_{sav}, and real estate RE_{sav} (which is a durable good) is

$$E_t \left\{ \sum_{\tau=t}^{\infty} \beta_{sav}^{\tau} \left[\begin{array}{c} \left(\frac{C_{sav,\tau}(j) - bbC_{sav,\tau-1}}{1-\sigma}\right)^{1-\sigma} \\ -\frac{\chi L_{sav,\tau}(j)^{1+\tau_L}}{1+\tau_L} + \gamma_{sav} \log(RE_{sav,\tau}(j)) \end{array} \right] \right\}, \tag{3}$$

where E_t denotes the expectation conditional on information set at date t, $\beta_{sav} \in (0,1)$ is the discount factor, $bb \in (0,1)$ is the external habit parameter, $1/\sigma > 0$ is the elasticity of intertemporal substitution, $\chi > 0$ is the weight of labor, $\tau_L > 0$ is the reciprocal of the Frisch elasticity of labor supply and $\gamma_{sav} > 0$ is the weight of housing services. The budget constraint

[7]The reaction function does neither imply nor intend to model a complete control of the monetary authority over long-term interest rate developments. The latter corresponds to actual recent policy experience by the Bank of Japan and its yield-curve control policy. See Dell'Ariccia et al. (2018).

[8]For instance, in the case of the Home country $n(\lambda_{sav} + \lambda_{bor} + \lambda_{res} + \lambda_{ent}) = n$.

is

$$\begin{aligned}
&B_{sav,t}(j) + B^{REA}_{sav,t}(j) + P^{long}_t B^{long}_{sav,t}(j) + D_{sav,t}(j) + V_t(K^{bank}_{sav,t}(j) - K^{bank}_{sav,t-1}(j)) \\
&= R^B_{t-1} B_{sav,t-1}(j) + (1 - \Gamma_{B,t-1}) \left(R^{B,REA}_{t-1} B^{REA}_{sav,t-1}(j) \right) \\
&+ P^{long}_t R^{long}_t B^{long}_{sav,t-1}(j) + R^D_{t-1} D_{sav,t-1}(j) + \Pi_{bank,t} K^{bank}_{sav,t-1}(j) \\
&+ W_t(j) L_{sav,t}(j) - \Gamma_{W,t}(j) \\
&+ \Pi^{prof}_t - Q^{RE}_t \left(RE_{sav,t}(j) - RE_{sav,t-1}(j) \right) - P_{C,t} C_{sav,t}(j) - TAX_t \\
&- \frac{\phi_{sav,dep}}{2} \left(D_{sav,t}(j) - \overline{D_{sav}} \right)^2 - \frac{\phi_{sav,equity}}{2} \left(K^{bank}_{sav,t}(j) - \overline{K^{bank}_{sav}} \right)^2 \\
&- \frac{\phi^I_{sav,long}}{2} \left(P^{long}_t B^{long}_{sav,t}(j) - share^{long}_{B_{sav}} \frac{\overline{P^{long} B^{long}}}{n\lambda_{sav}} \right)^2 - \phi^{II}_{sav,long} P^{long}_t B^{long}_{sav,t}(j), \qquad (4)
\end{aligned}$$

where B_{sav}, B^{REA}_{sav}, and D_{sav} are the positions in domestic riskless one-period (short-term) nominal bonds, international riskless one-period (short-term) nominal bonds, and domestic bank deposits, respectively. They are all denominated in euro currency and pay the (gross) the interest rates R^B, $R^{B,REA}$, R^D at the beginning of period t. The variable B^{long}_{sav} is the domestic long-term domestic sovereign bond held by savers. Its price is P^{long}. Following Woodford (2001), the bond is formalized as a perpetuity paying an exponentially decaying coupon $\kappa^{long}(0, 1]$ so that the gross interest rate is

$$R^{long}_t = \frac{1}{P^{long}_t} + \kappa^{long}. \qquad (5)$$

Bank equities held by savers K^{bank}_{sav} have price V and pay the dividend Π_{bank}. The variable Q^{RE} is the price of real estate RE_{sav} (we assume zero-depreciation of real estate), and Π^{prof} represents profits, rebated in a lump-sum way, from ownership of non-financial domestic firms other than capital producers. The term P_C is the price of the final non-durable consumption goods. The variable $TAX > 0$ is lump-sum tax paid to the government.

The term Γ_B is the adjustment cost on the internationally traded bond,

$$1 - \Gamma_{B,t} \equiv \left(1 - \phi_{B1} \frac{exp(\phi_{B2}[B^{REA}_{sav,t} - \overline{B^{REA}_{sav}}]) - 1}{exp(\phi_{B2}[B^{REA}_{sav,t} - \overline{B^{REA}_{sav}}]) + 1} \right), \qquad (6)$$

where ϕ_{B1}, $\phi_{B2} > 0$. The term $\overline{B^{REA}_{sav}}$ is the steady-state position of the representative Home saver in the market.[9]

The parameters $\phi_{sav,dep}, \phi_{sav,equity}, \phi^{I}_{sav,long}, \phi^{II}_{sav,long} > 0$ represent the adjustment costs of bank deposits, bank equities, and long-term sovereign bonds, respectively. The terms $\overline{D_{sav}}$ and $\overline{K^{bank}_{sav}}$, are the steady-state holdings of bank deposits and bank equities, respectively. The parameter $0 < share^{long}_{B_{sav}} < 1$ is the share of overall supply of domestic long-term sovereign bonds, $\overline{B^{long}}$, held in steady state held by all savers, and $\overline{P^{long}}$ the price of the bond in steady state.[10] The variables $W(j)$ and $L_{sav}(j)$ are the nominal wages and the labor supplied by the generic saver j, respectively. They enter the following firms' demand equation

$$L_{sav,t}\left(j\right) = \left(\frac{W_t(j)}{W_t}\right)^{-\sigma_L} L_{sav,t}. \tag{7}$$

where $\sigma_L > 1$ is the elasticity of substitution among different labor varieties supplied by different households under monopolistic competition (households are nominal wage-setters) and W is the nominal wage paid to the overall labor bundle (a composite of different labor varieties). The term Γ_W is the wage quadratic adjustment cost paid in terms of the total wage bill,

$$\Gamma_{W,t}(j) \equiv \frac{\psi_W}{2}\left(\frac{W_t(j)/W_{t-1}(j)}{\Pi_{t-1}^{ind_W}\overline{\Pi}_{EA}^{1-ind_W}} - 1\right)^2 W_t L_{sav,t}, \tag{8}$$

where the parameter $\psi_W > 0$ measures the degree of nominal wage rigidity, L_{sav} is the total amount of labor and $0 \leq ind_W \leq 1$ is a parameter that measures indexation to the previous-period (gross) price inflation and $1 - ind_W$ to the EA central bank (constant) gross inflation target.

Under the assumption of symmetric equilibrium, the representative saver optimally chooses consumption, labor, real estate, short-and long-term bonds, bank deposits, and bank equities to maximize utility, subject to the budget constraint (Eq. 4) and to the demand for labor (Eq. 7). As the resulting first order conditions are standard, we do not report them to save on space.[11]

[9] Adjustment costs on asset positions of households and banks (see Section 2.6) are needed to make the model stationary, given the assumption of incomplete financial markets. See Benigno (2009).

[10] These adjustment costs guarantee that deposits, equities, and long-term sovereign bonds follow a stationary process, and the economy converges to the steady state.

[11] They are available upon request. Asset choices imply no-arbitrage conditions, that, up to first order, equate the expected returns on the different assets. The optimization problem for the choice of the optimal amount of work offered is solved only by savers. Other households supply the same amount of working hours and get the same hourly wages as those of savers. A version of the model with household-specific labor supply is also available.

2.3.2 Borrowers

The generic borrower j' discounts the future more heavily than the savers ($\beta_{bor} < \beta_{sav}$).[12] Each borrower maximizes the lifetime utility function, similar to the one of savers (Eq. 3) subject to the budget and borrowing constraints. The budget constraint of the generic borrower j' is

$$\begin{aligned} Loan_{bor,t}(j') &= R^{Loan}_{ret\_bor,t-1} Loan_{bor,t-1}(j') + W_t L_{bor,t}(j') \\ &-P_{C,t} C_{bor,t}(j') - Q^{RE}_t \left(RE_{bor,t}(j') - RE_{bor,t-1}(j') \right), \end{aligned} \tag{9}$$

where $Loan_{bor}$ are loans demanded to domestic retail banks, and $R^{Loan}_{ret\_bor}$ is the corresponding (gross) interest rate.

The borrower j' obtains (one-period) loans from banks subject to a collateral constraint as in Iacoviello (2005) and Kiyotaki and Moore (1997),

$$- Loan_{bor,t}(j') \leq m_{bor} E_t \left(\frac{Q^{RE}_{t+1} RE_{bor,t}(j')}{R^{Loan}_{ret\_bor,t}} \right), \tag{10}$$

where $m_{bor} \in [0, 1]$ is the borrowers' loan-to-value (LTV) ratio, that limits their possibility to get loans.

The representative borrower optimally chooses consumption, real estate, and loans to maximize utility subject to the budget constraint (Eq. 9) and borrowing constraint (Eq. 10).

2.3.3 Restricted households

The generic restricted household j'' maximizes the utility function

$$E_t \left\{ \sum_{\tau=t}^{\infty} \beta^{\tau}_{res} \left[\left(\frac{C_{res,\tau}(j'') - bbC_{res,\tau-1}}{1-\sigma} \right)^{1-\sigma} - \frac{\chi L_{res,\tau}(j'')^{1+\tau_L}}{1+\tau_L} \right] \right\}, \tag{11}$$

where $\beta_{res} \in (0, 1)$ is the discount factor, $bb \in (0, 1)$ is the external habit parameter, C_{res} is consumption, and L_{res} is labor. The restricted household invests in long-term sovereign bonds, holds constant shares of domestic capital goods producers (see section 2.5) and, thus, indirectly

This simplifying assumption does not affect our results.

[12] As in Iacoviello (2005), it is assumed that borrowers are more impatient than savers, i.e., their discount factor is relatively low.

invests in domestic physical capital. The budget constraint is

$$
\begin{aligned}
&P_t^{long} B_{res,t}^{long}(j'') = P_t^{long} R_t^{long} B_{res,t-1}^{long}(j'') + W_t L_{res,t}(j'') \\
&+(1 - share_{k\_entr}) \left(R_t^K K_{t-1} - P_{I,t} I_t\right) - P_{C,t} C_{res,t}(j'') \\
&-\frac{\phi_{res,long}}{2} \left(P_t^{long} B_{res,t}^{long}(j'') - share_{B_{res}}^{long} \frac{\overline{P^{long} B^{long}}}{n \lambda^{res}}\right)^2 ,
\end{aligned} \tag{12}
$$

where $(1 - share_{k\_entr})$ is the share of capital goods producers held by the restricted households ($0 < share_{k\_entr} < 1$). It multiplies profits rebated by capital producers (K is the domestic physical capital stock, R^K its return, I investment in physical capital and P_I its price). The parameter $\phi_{res,long} > 0$ measures the adjustment cost on long-term sovereign bonds. The term $0 < share_{B_{res}}^{long} < 1$ is the share of (overall) long-term sovereign bonds held in steady state by restricted households.

In the symmetric equilibrium the representative restricted household optimally chooses consumption and long-term sovereign bonds to maximize utility subject to the budget constraint.

2.4 Entrepreneurs

The generic entrepreneur e maximizes the intertemporal utility function

$$
E_t \left\{ \sum_{\tau=t}^{\infty} \beta_{entr}^{\tau} \left[\frac{\left(C_{entr,\tau}(e) - bbC_{entr,\tau-1}\right)^{1-\sigma}}{(1-\sigma)} \right] \right\}, \tag{13}
$$

where C_{entr} is consumption, $0 < \beta_{entr} < 1$ is the discount factor (entrepreneurs discount the future more heavily than savers, i.e., $\beta_{entr} < \beta_{sav}$).

The entrepreneur borrows from domestic banks and holds a constant share of capital producers. The budget constraint is

$$
\begin{aligned}
&Loan_{entr,t}(e) - Loan_{entr,t-1}(e) R_{ret\_entr,t-1}^{Loan} = share_{k\_entr} \left(R_t^K K_{t-1} - P_{I,t} I_t\right) \\
&+R_t^{RE} RE_{entr,t-1}(e) - P_{C,t} C_{entr,t}(e) - Q_t^{RE} \left(RE_{entr,t}(e) - RE_{entr,t-1}(e)\right),
\end{aligned} \tag{14}
$$

where $Loan_{entr} < 0$ are loans demanded to domestic banks, $R_{ret\_entr}^{Loan}$ is the gross interest rate on loans paid by the entrepreneurs, RE_{entr} is real estate, R^{RE} is the (net) return from renting real estate to domestic firms on a period-by-period basis.

The borrowing constraint, similar to the one of borrowers, is

$$- Loan_{entr,t}(e) \leq m_{entr} E_t \left\{ \frac{Q^{RE}_{t+1} RE_{entr,t}(e)}{R^{Loan}_{ret\_entr,t}} \right\}, \tag{15}$$

where $0 \leq m_{entr} \leq 1$ is the LTV ratio.

In the symmetric equilibrium the representative entrepreneurs optimally chooses consumption, real estate, and long-term sovereign bonds to maximize utility subject to the budget and the borrowing constraints.

2.5 Capital goods producers

There is a continuum of capital producers having the same size as that of the regional economy and acting under perfect competition. The generic capital goods producer c is owned by domestic entrepreneurs and restricted households. Its stochastic discount factor is therefore a weighted sum of the entrepreneurs' and restricted households' stochastic discount factors, with weights equal to the corresponding population shares.

The capital accumulation law is

$$K_t(c) = (1 - \delta) K_{t-1}(c) + \left(1 - AC^I_t(c)\right) I_t(c), \tag{16}$$

where $0 < \delta < 1$ is the depreciation rate. The adjustment cost on investment, AC^I, is

$$AC^I_t(c) \equiv \frac{\phi_I}{2} \left(\frac{I_t(c)}{I_{t-1}(c)} - 1 \right)^2, \tag{17}$$

where $\phi_I > 0$ is a parameter. Investment I is a final non-tradable good, composed of intermediate tradable (domestic and imported) goods, its price is P_I.[13] Capital producers rent existing physical capital stock K_{t-1} in a perfectly competitive market at the nominal rate R^K to domestic firms producing intermediate goods. Profits are rebated in a lump-sum way to restricted house-

[13]Because of the adjustment costs on investment, a "Tobin's Q" holds.

holds and entrepreneurs according to the corresponding shares $(1 - share_{k\_entr})$ and $share_{k\_entr}$, respectively.

The representative capital producer optimally chooses the end-of-period capital K_t and investment I_t subject to the law of capital accumulation, the adjustment costs on investment, and taking all prices as given.

2.6 Banks

There is a banking sector in both Home and REA economies. Each banking sector is composed by intertwined wholesale and retail branches.[14]

The wholesale branch acts under perfect competition. It maximizes profits by taking all interest rates as given and subject to a bank capital requirement. It (optimally) issues deposits and equities (i.e., bank capital) to domestic savers, buys domestic long-term sovereign bonds and makes resources available to the domestic bank retail sector.

The retail branch acts under monopolistic competition. There is a continuum of branches. Each of them differentiates the loans received from the wholesale banks. Each retail branch maximizes profits by optimally setting the interest rate on loans, taking as given (i) the interest rate paid on resources (i.e., wholesale loans) it gets from the wholesale banking sector and (ii) the demand for loans by domestic entrepreneurs and households (borrowers). It faces adjustment costs when setting the interest rates.

In what follows we initially describe the main equations of the wholesale sector and, subsequently, those of the retail sector.

2.6.1 Banks - Wholesale sector

There is a continuum of branches b_{wh} that act under perfect competition. The size of the continuum is the same as that of the region.

The optimal behavior of the generic wholesale branch is dictated by the combination of balance sheet (loans, long-term sovereign bonds, equities, deposits), capital requirement, and

[14] See also Gerali et al. (2010).

no-arbitrage conditions among returns on different asset and liabilities, implied by the price-taking profit maximization problem.

The balance sheet constraint in period t is

$$Loan_{wh,t}\left(b_{wh}\right)+P_t^{long}B_{bank,t}^{long}\left(b_{wh}\right)=D_{bank,t}\left(b_{wh}\right)+V_tK_{bank,t}\left(b_{wh}\right), \tag{18}$$

where $Loan_{wh}$ are total loans supplied by wholesale banks (to retail banks), B_{bank}^{long} are domestic long-term sovereign bonds, D_{bank} are deposits, VK_{bank} is the (nominal) amount of resources obtained by issuing equities K_{bank}.

Bank profits are equal to

$$\begin{aligned}
&R_{wh,t}^{Loan}Loan_{wh,t}\left(b_{wh}\right)+R_t^{long}B_{bank,t}^{long}\left(b_{wh}\right)-R_t^{D}D_{bank,t}\left(b_{wh}\right)\\
&-\frac{\phi_{bankcap}}{2}\left(V_tK_{bank,t}\left(b_{wh}\right)-\kappa Loan_{wh,t}\left(b_{wh}\right)\right)^2-\alpha_{bankcap}V_tK_{bank,t}\left(b_{wh}\right)\\
&-\phi_V\left(V_t-\overline{V}\right)K_{bank,t}\left(b_{wh}\right)-\frac{\phi_{bank,Loan}}{2}\left(Loan_t\left(b_{wh}\right)-\overline{Loan}\right)^2\\
&-\frac{\phi_{bank,long}^{I}}{2}\left(P_t^{long}B_t^{long}\left(b_{wh}\right)-share_{B_{bank}}^{long}\frac{\overline{B_{bank}^{long}}}{n}\right)^2\\
&-\phi_{bank,long}^{II}\overline{P^{long}}B_{bank,t}^{long}\left(b_{wh}\right),
\end{aligned} \tag{19}$$

where R^D, R_{wh}^{Loan}, and R^{long} are (gross) interest rates on deposits, on loans and on sovereign bonds, respectively. The term $\phi_{bankcap}>0$ is a parameter that measures the costs related to deviations from bank capital requirement, whose value is regulated by the parameter $\kappa\in(0,1)$, and $V_tK_{bank,t}-\kappa Loan_{wh,t}$ is the excess capital (with respect to the required level) in period t. The parameters $\alpha_{bankcap},\phi_V>0$ measure the cost of issuing equities and $\overline{V}$ is the steady-state price of the equity. The parameter $\phi_{bank,Loan}>0$ measures adjustment costs paid on loans, while the parameters $\phi_{bank,long}^{I}$, and $\phi_{bank,long}^{II}$ regulate the adjustment costs on sovereign bonds. The term $0<share_{B_{bank}}^{long}<1$ is the share of overall long-term sovereign bonds $\overline{B_{bank}^{long}}$ held in steady state ($\overline{P^{long}}$ the steady-state price of long-term bond) and $\overline{Loan_{wh}}$ the steady-state loans.

The representative wholesale bank maximizes profits on a period-by-period basis (static problem) with respect to loans, sovereign bonds, deposit, and equities, taking all prices and the balance sheet constraint as given.

2.6.2 Banks - Retail sector

There is a continuum of interest rate-setting retail branches b that act under monopolistic competition. The size of the continuum is the same as that of the region. Each branch differentiates loans of wholesale sector and lends to domestic entrepreneurs and to households (borrowers) in the corresponding markets.

The entrepreneur's demand for the generic retail loan is

$$Loan_{entr,t}\left(b,e\right)=\left(\frac{1}{n}\right)\left(\frac{R^{Loan}_{ret\_entr,t}\left(b\right)}{R^{Loan}_{ret\_entr,t}}\right)^{-\theta_{Loan}}Loan_{entr,t}\left(e\right), \tag{20}$$

where $\theta_{Loan}>1$ is a parameter measuring the elasticity of substitution among loans supplied by different branches. The setting of retail interest rate $R^{Loan}_{ret\_entr,t}\left(b\right)$ is subject to adjustment costs,

$$AC_{ret\_entr,t}\left(b\right)=\frac{\phi_{ret,loan}}{2}\left(\frac{R^{Loan}_{ret\_entr,t}\left(b\right)}{R^{Loan}_{ret\_entr,t-1}\left(b\right)}-1\right)^{2}R^{Loan}_{ret\_entr,t}Loan_{entr,t}\left(b\right), \tag{21}$$

where $\phi_{ret,loan}>0$ is a parameter (this allows us to get a gradual adjustment of retail interest rates to a given shock). Similar equations hold for loans to borrowers. The generic branch b sets the interest rate on loans to maximize profits, taking as given (i) the interest rate R^{Loan}_{wh} that it pays to borrow from the wholesale branch, (ii) the entrepreneurs' and borrowers' demand for loans $Loan_{entr}$ and $Loan_{bor}$, and (iii) subject to quadratic adjustment costs on the loans' interest rate.

The resulting FOCs imply that the interest rates on loans are given by (short-run time-varying) markups on the interest rates paid to the wholesale sector, for entrepreneurs. A similar FOC holds for interest rates on loans to borrowers. The implied profits are rebated to the savers, according to the owned amount of bank capital (equities).[15]

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[15]Savers hold bank equities, so they are the owners of banks. Return on bank capital is defined as

$$\Pi_{bank,t}=\left[R^{Loan}_{ret\_entr,t}Loan_{entr,t}+R^{Loan}_{ret\_bor,t}Loan_{bor,t}-R^{Loan}_{wh,t}Loan_{wh,t}\right]/K_{bank,t}. \tag{22}$$

Bank dividends are

$$DIV_{t}=\Pi_{bank,t}K_{bank,t}. \tag{23}$$

2.7 Calibration

The model is calibrated at quarterly frequency. The Home region is calibrated to a generic small-size EA region whose GDP is around 20% of the EA GDP.

Table 1 reports the steady-state great ratios. The overall outstanding amount of long-term sovereign bonds is set equal to 90% of EA annualized GDP. Savers hold 30% of them, restricted households and banks 25% each, the central bank 20%. In the Home region, the ratio of bank loans to entrepreneurs (borrowers) to GDP is equal to 59.0% (35.0%). In the REA region, the same ratio is equal to 79.0% (50.7%). The amount of bank capital (share to total loans) is equal to 10%. The size of deposits is residually determined so that the bank's balance sheet is satisfied, given the amounts of loans and bank capital.[16] The net foreign asset position is nil in steady state. The nominal short-term interest rate is set to 3% on an annualized basis, in line with Kiley (2018). The nominal long-term interest rate, paid by the sovereign bonds, to 7%. The steady-state annualized (target) inflation rate is set to 1.9%. The (net) growth rate of the overall economy (that follows a balanced growth path in steady state) to 0.8% in annualized terms.

Model parameters are set to match these ratios and in line with previous studies and estimates available in the literature.[17] Table 2 contains parameters for preferences and technology. The discount factor of EA savers is set to 0.99976. The discount factor of RW households is set to 0.99976 as well. The discount factor of restricted households determines the steady-state value of the long-term sovereign bond interest rate. It is set to 0.99. The discount factor of borrowers is set to 0.991. The weight of housing in the utility function is set to 0.01 in the case of savers (0.07 in the case of borrowers). In each region of the EA the population share of savers, borrowers, restricted households, and entrepreneurs are set to 30%, 50%, 10%, 10%, respectively.

Given the lack of micro-evidence on those shares, we set them to get a response of investment to the (benchmark) CSPP around four times as large as the response of consumption, in line with standard business cycle facts, and at the same time to calibrate the adjustment cost on investment to a rather standard value (i.e., 3.5, as reported in Table 4).[18]

[16] Deposits have to be interpreted in a broad sense as bank liabilities other than equities, because we do have securities issued by the banks.

[17] See the New Area Wide Model (NAWM; Warne et al. 2008), the Global Economy Model (GEM; Pesenti 2008), and the Euro Area and the Global Economy model (EAGLE; Bokan et al. 2018).

[18] Moreover, the chosen calibration of restricted households allows us to get in the benchmark case results for

Entrepreneurs' share of domestic capital producers is set to 50% in each EA region. The LTV ratios of Home and REA borrowers are set to 0.5 and 0.7, respectively. The LTV ratio of Home (REA) entrepreneurs is set to 0.40 (0.46). The bank capital requirement is set to 0.1 in both Home and REA, in line with existing regulatory requirements. Retail banking sector markups are set to rather small values.

Table 3 reports gross markups and the related elasticities of substitution among intermediate goods.

Table 4 reports real and nominal adjustment costs. The parameters in the adjustment costs on financial positions are calibrated so that they do not greatly affect the model dynamics and yet help to stabilize it. For the adjustment costs on long-term sovereign bond positions, parameters are calibrated so that the response of the long-term interest rates to the sovereign bond purchases by the central bank should be in line with existing evidence for the EA. Parameters measuring the stickiness of retail interest rates on loans are set to zero. So retail interest rates are flexible and the markup on wholesale interest rate is constant.[19]

Table 5 reports the parameterization of the systematic feedback rule followed by the central bank (Eq. 1). It targets EA-wide yearly consumer price inflation (the corresponding parameter is set to 3.7) and the output growth (the parameter is set to 0.4). Interest rate is set in an inertial way and thus its previous-period value enters the rule with a weight equal to 0.87. The values are identical for the corresponding parameters of the Taylor rule in the RW.

For the EA long-term sovereign bond purchase reaction function (Eq. 2), we set the parameter ϕ_{CB}, measuring the reactivity to inflation, to 3, in line with the value used in Burlon et al. (2019). The parameter ρ_{CB}, measuring inertia in (the stock of) purchases, is set to 0.98. The parameter $B_{CB}^{L,upper}$ is calibrated so that the purchases dictated by the reaction function, Eq. 2, can increase up to 4% of steady-state EA (annualized) GDP (a rather conservative value).

The chosen calibration yields impulse response functions to a standard monetary policy shock

the PSPP that are in line with Blattner and Joyce (2016). Specifically, using a small macro-finance BVAR model, they find that the ECB government bond purchases, as announced on 22 January 2015, reduced EA ten-year bond yields, on average, by around 30bps in 2015, and had a positive impact on the output gap and inflation in 2016, of the order of 0.2pp and 0.3pp respectively. The authors state that their estimates are likely to underestimate the overall impact of the ECB's purchases on interest rates and inflation, as they do not consider all possible transmission channels of the purchases programme. To save on space, we do not include the robustness analysis on the relative shares of the different household types. It is available upon request.

[19]We have conducted a sensitivity analysis on these stickiness parameters. Main results are not affected.

(+25 bp) for GDP and inflation in each EA region that are in line with the workhorse estimated models of the EA in the literature.[20]

3 Results

3.1 Simulated scenarios

Our goal is to evaluate to which extent the central bank can stabilize inflation by purchasing or selling long-term sovereign bonds in addition (or as an alternative) to controlling the (short-term) policy rate. In particular, we focus on systematic bond purchases when the (short-term) monetary policy rate hits the ZLB. We simulate alternative scenarios. Consistent with the New Normal framework, all of them should be thought of as relative to a baseline scenario in which the initial policy rate level is equal to 0.20pp (annualized terms).[21]

In the first simulated scenario a positive term premium shock (i.e., a financial shock) induces a drop in aggregate demand for consumption and investment. To stabilize prices, that decrease, the central bank reduces the policy rate according to the Taylor rule (Eq. 1), hitting the ZLB. The second scenario builds on the first one. The central bank, when facing the term premium shock, not only reduces the policy rate but also buys, in the secondary market, long-term sovereign bonds, according to the reaction function (Eq. 2).

We further explore the properties of the reaction function (Eq. 2) by changing the calibration of its parameters and by assuming that purchases react directly not only to the inflation gap but also to the long-term interest rate increase (relative to its steady-state level). We also consider a mix of negative shocks to (i) households' consumption preference and (ii) capital producers' marginal efficiency of investment to reduce aggregate demand, instead of the positive term premium shock. Thus, this recessionary scenario is driven by a real, as opposed to financial,

[20] See Warne et al. (2008) for example. Moreover, the responses of the main variables, in particular those of the long-term interest rates in response to previous PSPP announcement are similar to those reported in Burlon et al. (2018) and Burlon et al. (2017).

[21] The equilibrium level of the interest rate (the neutral interest rate) in the New Normal is supposed to be low but it is not known. Long-term bond purchases are less necessary the higher the neutral rate, because the central bank should have on average more space to decrease the (nominal) monetary policy rate in correspondence of a given deflationary shock. In this respect, our scenarios can be also thought as additive to a baseline transition phase, characterized by a gradual increase in the monetary policy rate from the currently very low level (i.e., zero) to a new (slightly) higher level, consistent with the equilibrium rate.

shock.

Finally, we consider a negative term premium shock, that favors aggregate demand. To stabilize the implied consumer price increase, the central bank can, alternatively: (i) augment the policy rate according to the Taylor rule (Eq. 1) and not sell long-term bonds; (ii) augment the policy rate and, simultaneously, sell the long-term sovereign bonds held in its balance sheet; (iii) augment the policy rate to a larger extent and not sell the long-term bonds (the Taylor coefficient in Eq. 1 is assumed to be higher than in the baseline calibration).

All simulations are run under the perfect foresight assumption. In all of them the government supply of long-term sovereign bonds is assumed to be constant at the steady-state level.[22]

Finally, in all simulations we take into account, in a deliberate parsimonious way, of a possible constraint on the amount of purchases, associated with possible technical and institutional issues (for example, scarcity of purchasable bonds).

3.2 Term premium increase

All charts plot results for the EA as a whole, given that region-specific responses are rather similar among each other (the shock is symmetric and the calibration of the two EA regions is similar). A temporary exogenous shock to the EA term premium is considered. The shock enters the no-arbitrage relation between short- and long-term interest rates that holds for the savers in both EA regions. It is such that the long-term interest rate increases by 0.5pp (peak level) and thereafter declines (see Fig. 2, scenario "ZLB").

Following the term premium increase, households increase their savings and gradually rebalance their wealth towards bonds, whose overall return has temporarily increased relative to the

[22]In each region there is a government budget constraint, that links short- and long-term sovereign debt to the public spending and tax flows. Public consumption is kept constant throughout all simulations. Lump-sum taxes endogenously adjust to stabilize short-run public debt relative to its steady-state level according to the fiscal rule

$$\frac{tax_t}{tax_{t-1}} = \left(\frac{b^s_{G,t}}{\bar{b}^s_G}\right)^{\phi_1} \left(\frac{b^s_{G,t}}{b^s_{G,t-1}}\right)^{\phi_2}, \tag{24}$$

where $\phi_1 > 0$ and $\phi_2 > 0$ are parameters. The rule calls for an increase (reduction) in lump-sum taxes tax (as a ratio to GDP) whenever the current-period short-term public debt (as a ratio to GDP) b^s_G is above (below) the target and/or it is increasing (decreasing) over time. By assumption, savers are the only ones to pay lump-sum taxes and to buy short-term bonds issued by the domestic government. In this way we do not allow wealth effects, associated with the distribution of short-term sovereign bonds and lump-sum taxation across different types of households, to affect the results.

baseline level. The banks sell the sovereign bonds to compensate for lower deposits. As reported in Fig. 2 and Fig. 3, savers substitute bonds for bank deposits. Moreover, banks reduce loans. The interest rates on deposits and loans (not reported to save on space) increase, consistent with the higher interest rate on sovereign bonds, the lower households' demand for bank deposits and the lower banks' supply of loans.

Facing the lower amount of loans and the higher interest rates, borrowers have to decrease consumption of both real estate services and non-durable goods (see Fig. 4 and Fig. 5, respectively). Similarly, entrepreneurs decrease consumption and demand of real estate (that they rent to firms in the domestic intermediate sector).[23] Moreover, because of their stake in capital producers, entrepreneurs decrease investment in physical capital. The latter decreases also because the restricted households, that have a stake in the capital producers as well, prefer to invest in long-term sovereign bonds given that the latter pay a higher interest rate. The drop in borrowers' and entrepreneurs' aggregate demand is amplified by the lower real estate prices, through the borrowing constraints (real estate is used as collateral).[24]

Given the lower aggregate demand, firms decrease production and, thus, labor demand. The implied lower wages and markup are transmitted to prices, that decrease (Fig. 6). The central bank reduces the short-term monetary policy rate, to stabilize price dynamics and macroeconomic conditions, as dictated by the Taylor rule (Eq. 1). The policy rate hits the ZLB and remains there for 5 quarters (the initial, before-shock, level of the policy rate is 0.2pp). The new, current and expected future, short-term monetary policy rate levels are not low enough to compensate for the higher term premium. The central bank cannot fully stabilize inflation by further lowering the monetary policy rate, and the recessionary effects of the term premium shock are amplified by the ZLB.

Fig. 2-6 (red dashed lines) also contain the effects of the term premium increase under the assumption that both the Taylor rule (Eq. 1) and the reaction function (Eq. 2) hold (scenario "ZLB+purchases"). Following the shock, consumer price inflation decreases below the EA central bank target. The central bank not only reduces the short-term interest rate according to the

[23]We assume aggregate supply of real estate is fixed in each region and that real estate is not internationally traded.

[24]Given that the real estate is assumed to be in fixed aggregate supply, savers buy the real estate sold by borrowers and entrepreneurs (see Fig. 4).

Taylor rule, but also buys long-term sovereign bonds, given the positive inflation gap. Ceteris paribus, higher central bank purchases favor the increase in the sovereign bond prices and, thus, the decrease in the long-term interest rate. In equilibrium, the measure is able to partially offset the increase in the long-term interest rate associated with the exogenous shock to the term premium (see Fig. 2). The (net) result is that the long-term interest rate increases to a lower extent than under the assumption of no-sovereign bond purchases. The stock of sovereign bond purchases by the central bank in each (Home and REA) market is roughly equal to 3% of the corresponding regional annualized GDP (peak value). The stock of purchases returns to zero in a rather gradual way.

Both households and banks sell the long-term sovereign bonds to the central bank (Fig. 2). Relative to the no-sovereign bond purchase scenario, deposits and loans will be lower and higher, respectively (Fig. 3). Banks can now sell the bonds at a a higher price than in the no-purchase scenario. Thus their balance sheet constraint is relaxed and can substitute loans for sovereign bond holdings and for deposit supply.

The relatively higher amount of loans makes resources available for borrowers' and entrepreneurs' real estate demand, consumption, and investment in physical capital (see Fig. 4 and Fig. 5). Thus, the drop in aggregate demand is less pronounced. In particular, the real estate price decreases to a lower extent, sustaining loans to borrowers and entrepreneurs. The short-term monetary policy rate stays at the ZLB for 4 quarters (instead of 5), consistent with the improved consumer price dynamics and economic activity (Fig. 6).

Overall, the direct intervention of the central bank in the long-term sovereign bond market, by stabilizing financial conditions (i.e., by partly counteracting the term premium increase), favors macroeconomic stabilization.

3.3 Properties of the central bank reaction function

We further investigate the properties of the reaction function (Eq. 2) by newly running the first scenario (term premium increase that reduces the EA policy rate to the ZLB) considering a lower value of the parameter ϕ_{CB}, that measures the responsiveness of purchases to the inflation gap. The parameter is set to 3 instead of 10 as in the benchmark calibration. Moreover, we also run that scenario assuming not only a lower value of ϕ_{CB}, but also a lower degree of inertia in the stock of purchases, measured by the parameter ρ_{CB} (it is set to 0.5 instead of 0.98).

Fig. 8 reports the results. The smaller the parameter ϕ_{CB} (scenario "Purchases less reactive to inflation") the lower the current and expected future purchases for a given inflation gap and, thus, the less aggressive the monetary response of the central bank. This implies that the monetary policy rate does not exit earlier from the ZLB. A similar picture emerges from setting both parameters ϕ_{CB} and ρ_{CB} to lower values (scenario "Purchases less reactive to inflation and less persistent").

We also consider the case of purchases reacting not only to the inflation rate, but also directly to the increase in the long-term interest rate. To this purpose, we newly simulate the exogenous term premium increase and modify Eq. 2, that holds in both Home and REA long-term sovereign bond markets, by adding a coefficient ϕ_{CB2} that positively reacts to the difference between the actual level of the region-specific long-term rate and its baseline value (weighted by the steady-state regional GDP, as a share of EA GDP).[25] This coefficient is set to 30 for illustrative purposes (the other two coefficients, ϕ_{CB} and ρ_{CB}, are set to their corresponding benchmark values, 3 and 0.98):

$$B^L_{CB,t} = \overline{B}^L_{CB} + min\left(B^{L,upper}_{CB}, \rho_{CB} B^L_{CB,t-1} + \phi_{CB}\left(\overline{\Pi} - \Pi_{EA,t}\right) + \phi_{CB2}\left(R^{long}_t - \overline{R^{long}}\right)\right). \tag{25}$$

Responses of the GDP, inflation, and long-term interest rate under the new purchasing reaction function (scenario "Purchases reacting also to long-term rate") are not much different from those under the standard purchasing function. For one reason, i.e., that under the modified function the purchases achieve their upper limit in the short run, and thereafter rapidly return to their baseline level.

To further explore the role of the upper limit to purchases, we remove it from the simulation (scenario "Purchases reacting also to long-term rate+no upper limit to purchases"). Purchases now increase up to 7% of annualized (baseline) EA GDP. The long-term rate increases to a lower extent, favoring GDP and price dynamics. The monetary policy rate stays at the ZLB for 4 quarters (instead of 5).

[25]For a similar specification, see Carlstrom et al. (2017).

To sum up, results suggests that the long-term sovereign bond purchases must to be deployed in a sufficiently large amount and reinvested in order to be effective. *De jure* or *de facto* upper bounds can constrain the reaction function of the central bank and, thus, the capability of the central bank to stabilize inflation.

We investigate the stabilization role of asset purchases also in the case of a negative shock to EA aggregate demand, that induces a drop in consumption and investment in physical capital (it is a combination of negative investment-specific shock to capital producers and consumption preference shocks to all households).

Fig. 7 plots the responses of the main variables (scenario “ZLB”) in the case of no-asset purchases. Thus, the short-term rate is the only monetary policy instrument.

The central bank reduces the monetary policy rate according to the Taylor rule, given the decrease in EA inflation relative to the target. Differently from previous simulations, he long-term interest rate now decreases, because there is no positive term premium shock and the long-term rate is affected by the lower current and expected short-term rates through the expectation hypothesis, that holds for savers. Moreover, restricted households are (directly) affected by the negative consumption preference shock and, indirectly, by the negative investment-specific shock, given that they hold shares of the capital producers. Thus, they reduce consumption and shift their savings towards investment in long-term sovereign bonds, contributing to the increase in their prices and, thus, the decrease in the long-term interest rate. As in the case of the term premium shock, the monetary policy rate hits the ZLB.

The simulation is newly run under the assumption that the non-standard measures are implemented in a systematic way (scenario “ZLB+purchases”), according to the purchasing reaction function (Eq. 2). Given the positive EA inflation gap, the EA central bank increases its purchases. The long-term interest rate decreases more than in the case of no-asset purchases, favoring the stabilization of consumption and investment in physical capital. The relative improvement in price dynamics and macroeconomic conditions implies that the policy rate increases at a faster rate, as dictated by the EA Taylor rule, once out of the ZLB.

Finally, we consider the case of the central bank that follows the reaction function (25) and, thus, reacts to the long-term rate (scenario “ZLB+purchases reacting to LT rate”). The rule does not favor inflation stabilization, because the central bank sells bonds in response to the lower long-term rate. Aggregate demand decreases to a larger extent than in the case of no-reaction to the long-term rate, inducing firms to further decrease prices of goods and services.

Overall, the results of this section confirm that sovereign bond purchases, by directly affecting the long-term interest rate, can complement the standard monetary policy measures, i.e., the reductions in the policy rate, in stabilizing price dynamics when the ZLB is binding. Purchases should react to the inflation gap, while the (direct) systematic reaction to interest rate dynamics can be effective only in the case of recessionary financial shocks but detrimental in the case of recessionary real shocks.

3.4 Term premium decrease

We also consider the case of an exogenous decrease in the EA term premium (a favorable financial shock) that induces a reduction in the long-term rate equal to 0.5pp.

Fig. 9 plots the responses of the main variables (scenario "Lower term premium"). The lower term premium induces households to increase consumption and investment. Firms match the higher aggregate demand by increasing aggregate supply. The higher production is sustained by the increase in employment and physical capital. Firms increase prices as well, albeit to a lower extent than production given the presence of (short-term) nominal price rigidities.

The size of the responses is in absolute terms lower than the one obtained in the case of a term premium increase. The reason is that the short-term policy rate is not subject to an upper bound and, thus, the central bank can increase it as dictated by the Taylor rule to stabilize price dynamics (in line with the target) and general macroeconomic conditions. The higher real (current and expected) interest rates induce households and firms to limit their increase in the demand for consumption and investment.

Fig. 9 shows the responses of the main macroeconomic variables when the central bank not only raises the short-term monetary policy rate but also intervenes in the long-term sovereign market (scenario "Sales"). The central bank sells the bonds held in the balance sheet, according to the reaction function, because the actual inflation rate is higher than the target. The long-term rate falls to a lower extent than in the previous scenario (no long-term bond purchases by central bank). Thus, households and firms increase their aggregate demand for consumption and investment to a lower extent. Interestingly, the short-term interest rate increases to a lower extent as well, consistent with the Taylor rule (Eq. 1) and the lower increase in inflation (and economic activity).

The central bank, instead of selling long-term sovereign bonds to react to the term premium decrease, could (credibly and systematically) commit to a Taylor rule having a high value of the Taylor coefficient ρ_π. Fig. 9 also reports the results when the coefficient is set to 5 instead of 3.7 as in the baseline calibration. The scenario is labeled as "Higher Taylor coefficient". Responses are similar to those obtained when the long-term sovereign bonds are purchased.[26]

Overall, the lack of an upper bound to the policy rate makes the latter a flexible instrument in the case of inflation higher than the target. Thus, the need for the central bank to sell long-term bonds is less compelling.

4 Conclusion

In this paper we have simulated the effects of non-standard monetary policy measures (i.e., long-term sovereign bonds purchases and sales by the central bank) in the New Normal, characterized by a low equilibrium real interest rate. According to our results, systematic long-term sovereign bond purchases help stabilize macroeconomic conditions when the short-term monetary policy rate hits the ZLB. To be effective, purchases must be sufficiently sizable and persistent when economic conditions deteriorate. Thus, possible (*de jure* or *de facto*) upper limits to purchases can be an issue in the case of sufficiently deflationary shocks. Purchases are an effective stabilization tool after positive shocks to the sovereign term premium (a financial shock) and negative shocks to aggregate demand (real shocks). However, purchases reacting also to the long-term rates

[26] According to Simon Potter ("Gradual and predictable - reducing the size of the Federal Reserve's balance sheet," Remarks at SUERF – The European Money and Finance Forum, New York City, October 11, 2017), *'there is always a risk that events could unfold differently from expectations. In particular, central banks have had little directly relevant past experience with the impact of such a reduction in holdings of domestic securities and in reserves. One relevant experience, of course, was the 2013 "taper tantrum," which shows that markets can have outsized reactions to changes in balance sheet policy even before they happen. Moreover, experience with asset purchase programs, both here and abroad, clearly demonstrates that market volatility can ensue from balance sheet policy changes that market participants perceive as surprising, unclear, or rapid. All of this indicates to me that, at policy turning points like these, central banks should carefully and clearly communicate their intentions, provide as much transparency as possible, and make transitions in policy implementation as slowly as overall macroeconomic policy objectives permit.'*

are effective in the case of recessionary financial shocks but not in the case of recessionary real shocks. Finally, in the case of expansionary shocks, a sufficiently aggressive systematic increase in the short-term monetary policy rate (dictated by the Taylor rule) can substitute for central bank sales of long-term sovereign bonds.

Overall, our analysis suggests that central bank asset purchases can ameliorate the negative consequences for consumer price dynamics of adverse shocks and the ZLB in the New Normal.

The analysis can be extended along several dimensions. Synergies between asset purchases and other types of non-standard measures (e.g., forward guidance on the short-term monetary policy rate) can be assessed. Or the interaction between monetary and fiscal policy measures, focusing in particular on public debt management by the fiscal authority. We leave these issues for future research.

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Table 1: Main variables

	H	REA	RW
Macroeconomic variables			
Private consumption	59.4	55.6	50.7
Public consumption	20.0	21.0	21.0
Investment	20.6	23.4	28.3
Imports	25.4	19.4	3.5
Home imports from	–	11.5	13.9
REA imports from	2.7	–	16.5
RW imports from	0.5	3.0	–
Share of world	3.1	14.7	82.2
Financial variables			
Long-term public debt	90	90	–
shares (%) held by			
Savers	30	30	–
Restricted households	25	25	–
Banks	25	25	–
Central bank	20	20	–
Bank capital	10.0	10.0	–
Bank loans to entrepreneurs	59.0	79.0	–
Bank loans to borrowers	35.2	50.7	–
Duration long-term sovereign bonds	32.0	32.0	–
Net foreign asset position	0.0	0.0	0.0

Note: H = Home; REA = rest of the euro area; RW = rest of the world. Long-term sovereign bonds and loans as % of annualized GDP; bank capital as % of total loans; share of world GDP is the regional GDP-to-world GDP ratio (%); duration of long-term sovereign bonds is measured as number of quarters; other variables are % of GDP.

Table 2: Preferences and technology

Parameter	H	REA	RW
Savers' discount factor $\beta_{sav}, \beta^*_{sav}, \beta^{**}$	0.99976	0.99976	0.99976
Borrowers' discount factor $\beta_{bor}, \beta^*_{bor}$	0.991	0.991	–
Entrepreneurs' discount factor $\beta_{entr}, \beta^*_{entr}$	0.99	0.99	–
Intertemporal elasticity of substitution $1/\sigma$	1.0	1.0	1.0
Habit (households and entrepreneurs) bb	0.8	0.8	0.8
Inverse of Frisch elasticity of labor supply τ	3.0	3.0	3.0
Savers' weight on housing services γ_{sav}	0.01	0.01	–
Borrowers' weight on housing services γ_{bor}	0.07	0.07	–
Share of savers λ_{sav}	0.3	0.3	1.0
Share of restricted λ_{restr}	0.1	0.1	1.0
Share of borrowers λ_{bor}	0.5	0.5	–
Share of entrepreneurs λ_{entr}	0.1	0.1	–
Borrowers' LTV ratio m_{bor}	0.5	0.7	–
Entrepreneurs' LTV ratio m_{entr}	0.4	0.46	–
Bank capital requirement κ	0.1	0.1	–
Depreciation rate of capital δ	0.025	0.025	0.025
Intermediate goods			
Substitution between factors of production	0.93	0.93	0.93
Bias towards capital	0.50	0.60	0.55
Bias towards housing	0.05	0.05	–
Final consumption goods			
Subst. btw. tradable and non-tradable goods	0.50	0.50	0.50
Bias towards tradable goods	0.80	0.50	0.50
Subst. btw. dom. and imported goods	1.50	1.50	1.50
Bias towards domestic tradable goods	0.68	0.60	0.90
Final investment goods			
Subst. btw. tradable and non-tradaable goods	0.50	0.50	0.50
Bias towards tradable goods	0.78	0.70	0.70
Subst. btw. dom. and imported goods	1.50	1.50	1.50
Bias towards domestic tradable goods	0.50	0.50	0.90

Note: H = Home; REA = rest of the euro area; RW = rest of the world. "*" refers to REA; "**" to RW.

Table 3: Gross markups

Markups (elasticities of substitution among brands)			
	Intermediate tradable goods	Intermediate non-tradable goods	Wages
H	1.2 ($\theta_T = 6.0$)	1.33 ($\theta_N = 4.0$)	1.33 ($\psi = 4.0$)
REA	1.2 ($\theta_T^* = 6.0$)	1.33 ($\theta_N^* = 4.0$)	1.33 ($\psi^* = 4.0$)
RW	1.2 ($\theta_T^{**} = 6.0$)	1.33 ($\theta_N^{**} = 4.0$)	1.33 ($\psi^{**} = 4.0$)

Note: H = Home; REA = rest of the euro area; RW = rest of the world. "*" refers to REA; "**" to RW.

Table 4: Adjustment costs

Parameter	H	REA	RW
Savers			
Long-term sovereign bond $\phi^{I}_{sav,long}$, $\phi^{I*}_{sav,long}$	0.00016	0.00016	–
Long-term sovereign bond $\phi^{II}_{sav,long}$, $\phi^{II*}_{sav,long}$	0.0099	0.0099	–
International bond ϕ_{B1}, ϕ^{**}_{B1}	0.01	–	0.01
International bond ϕ_{B2}, ϕ^{**}_{B2}	0.01	–	0.01
Bank equities $\phi_{sav,equity}$, $\phi^{*}_{sav,equity}$	0.01	0.01	–
Bank deposits $\phi_{sav,dep}$, $\phi^{*}_{sav,dep}$	0.00001	0.00001	–
Restricted households			
Long-term sovereign bond $\phi_{res,long}$, $\phi^{*}_{res,long}$	0.00016	0.00016	–
Banks			
Capital $\phi_{bankcap}$, $\phi^{*}_{bankcap}$	0.001	0.001	–
Capital $\alpha_{bankcap}$, $\alpha^{*}_{bankcap}$	1.007	1.007	–
Capital ϕ_{V}, ϕ^{*}_{V}	0.2	0.2	–
Loans $\phi_{bank,loan}$, $\phi^{*}_{bank,loan}$	0.000001	0.000001	–
Long-term sovereign bond $\phi^{I}_{bank,long}$, $\phi^{I*}_{sav,long}$	0.0001	0.0001	–
Long-term sovereign bond $\phi^{II}_{bank,long}$, $\phi^{II*}_{sav,long}$	-0.0099	-0.0099	–
Retail interest rates $\phi_{ret,loan}$, $\phi^{*}_{ret,loan}$	0.00	0.00	–
Firms			
Physical capital ϕ_{I}, ϕ^{*}_{I}, ϕ^{**}_{I}	3.5	3.5	3.5
Wage and Prices			
Nominal wages κ_{W}, κ^{*}_{W}, κ^{**}_{W}	800	800	800
Home intermediate non-tradable goods	700	700	700
Home intermediate tradable goods	600	600	600
REA intermediate tradable goods	600	600	600
RW intermediate tradable goods	600	600	600

Note: H = Home; REA = rest of the euro area; RW = rest of the world. "*" refers to REA; "**" to RW.

Table 5: Monetary policy rule and reaction function

Parameter	EA	RW
Monetary policy rule		
Lagged interest rate ρ_R, ρ_R^{**}	0.87	0.87
Inflation ρ_Π, ρ_Π^{**}	3.70	3.70
GDP growth $\rho_{GDP}, \rho_{GDP}^{**}$	0.10	0.10
EA reaction function		
Inflation ϕ_{CB}	3.00	
Inertia ρ_{CB}	0.98	

Note: EA = euro area; RW = rest of the world. "**" to RW.

Figure 1: Financial structure of the model

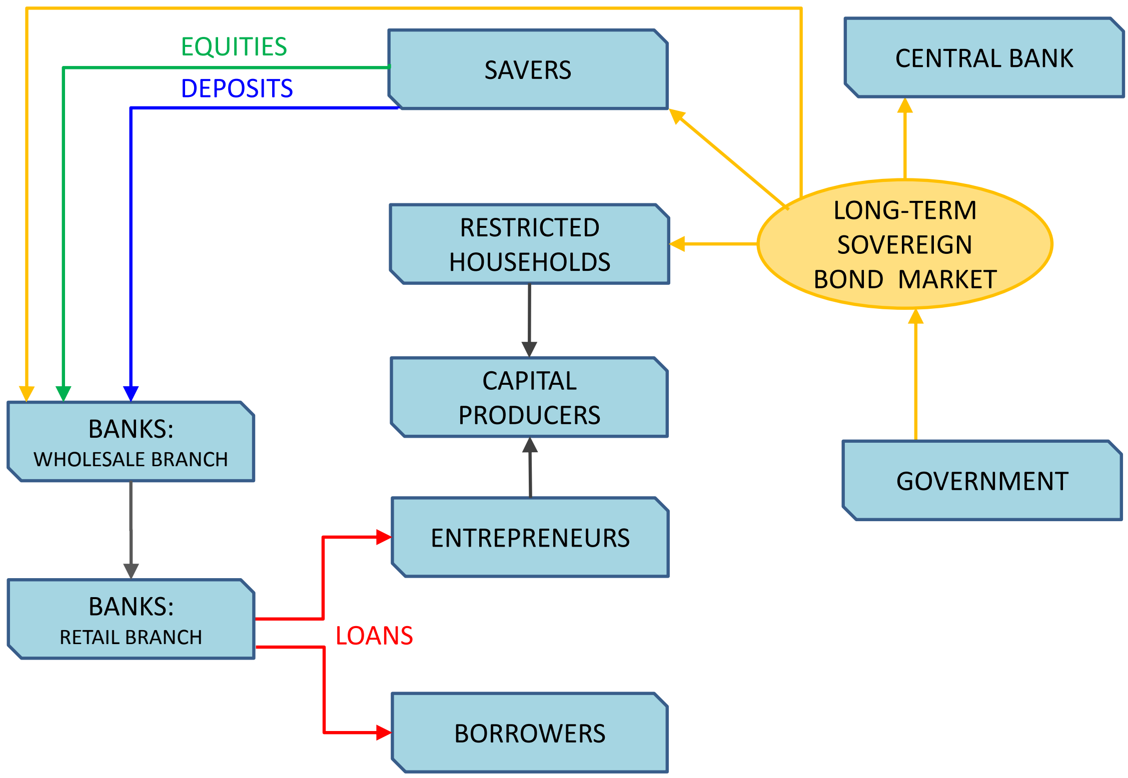
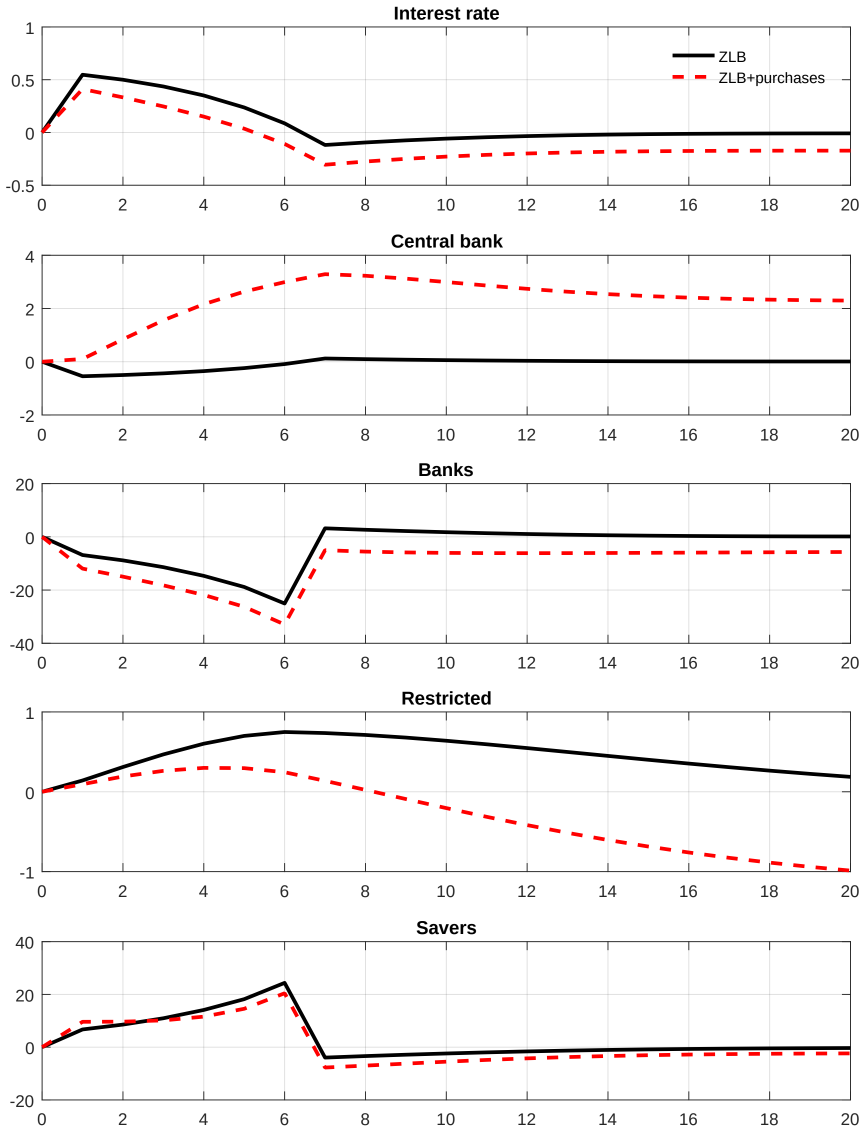
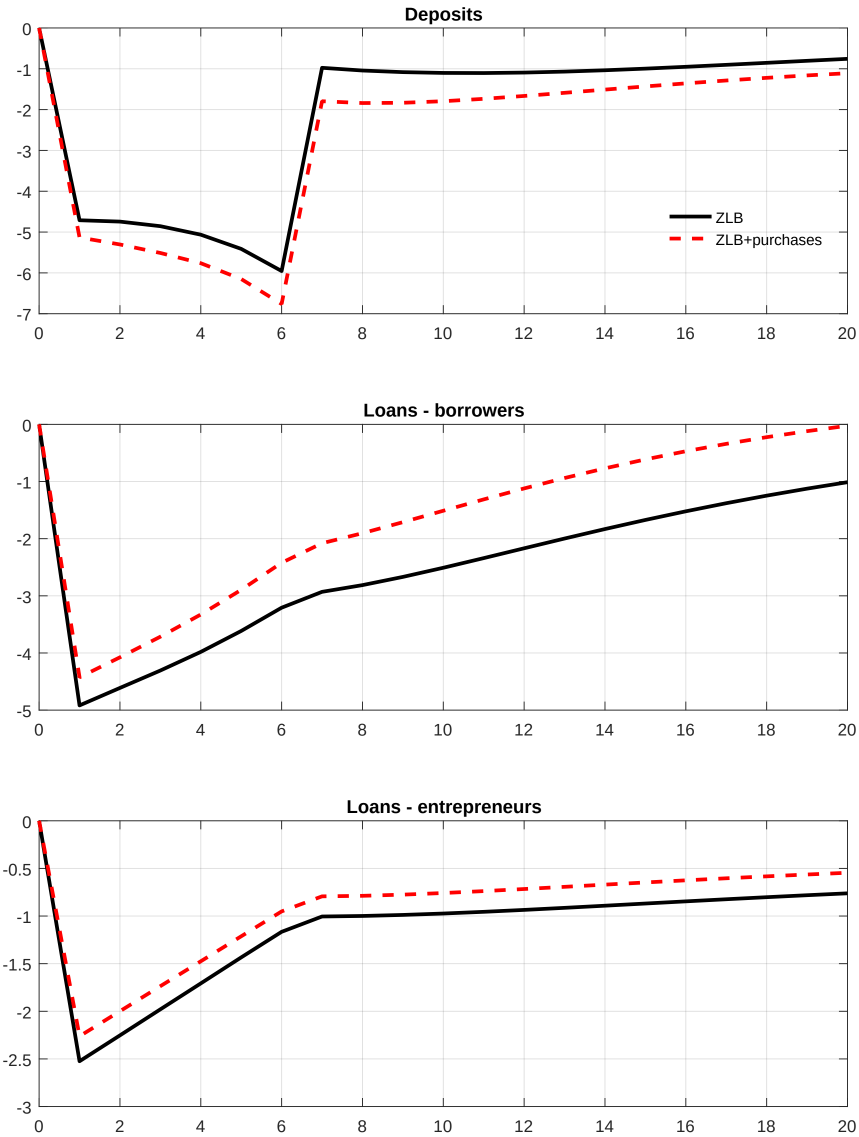


Figure 2: EA positive term premium shock: EA long-term sovereign bond market



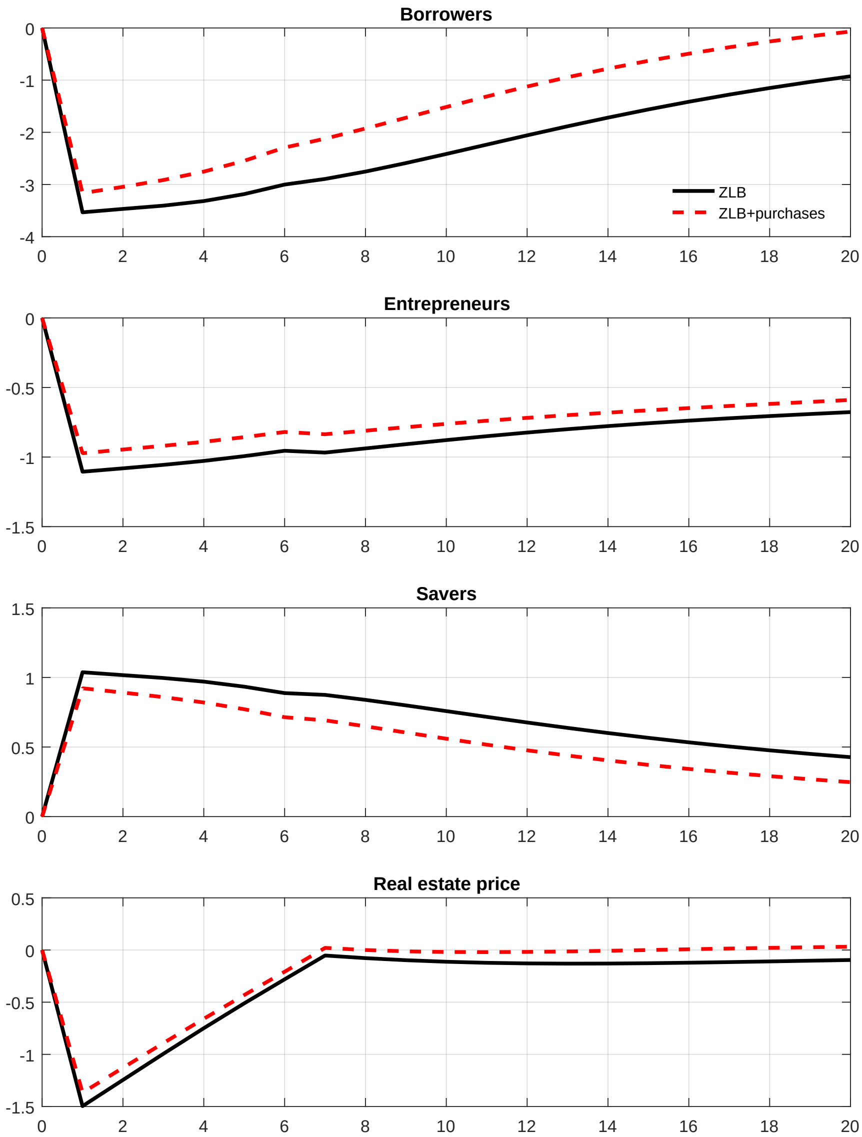
Horizontal axis: quarters; vertical axis: interest rate, annualized pp deviations from baseline; central bank purchases, % of baseline (annualized) GDP, pp deviations, households' positions, % deviations.

Figure 3: EA positive term premium shock: EA bank deposits and loans



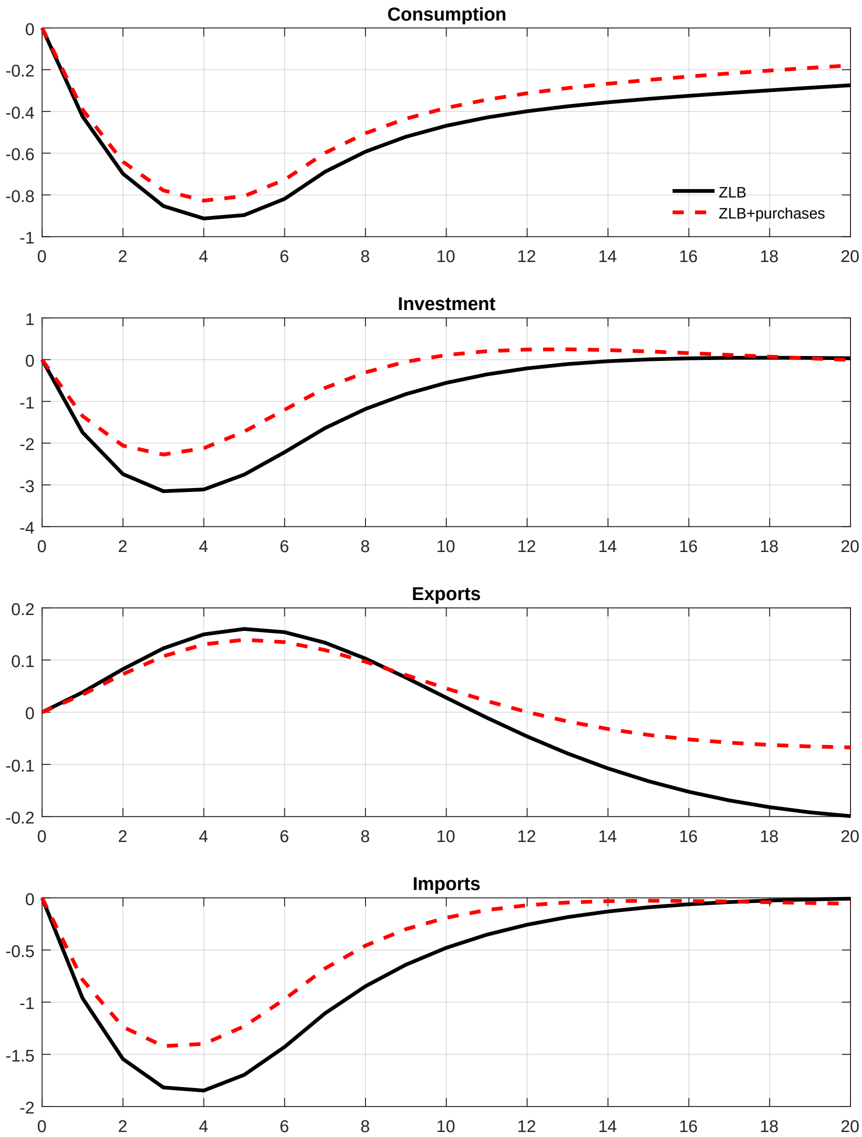
Horizontal axis: quarters; vertical axis: % deviations from baseline.

Figure 4: EA positive term premium shock: EA real estate market



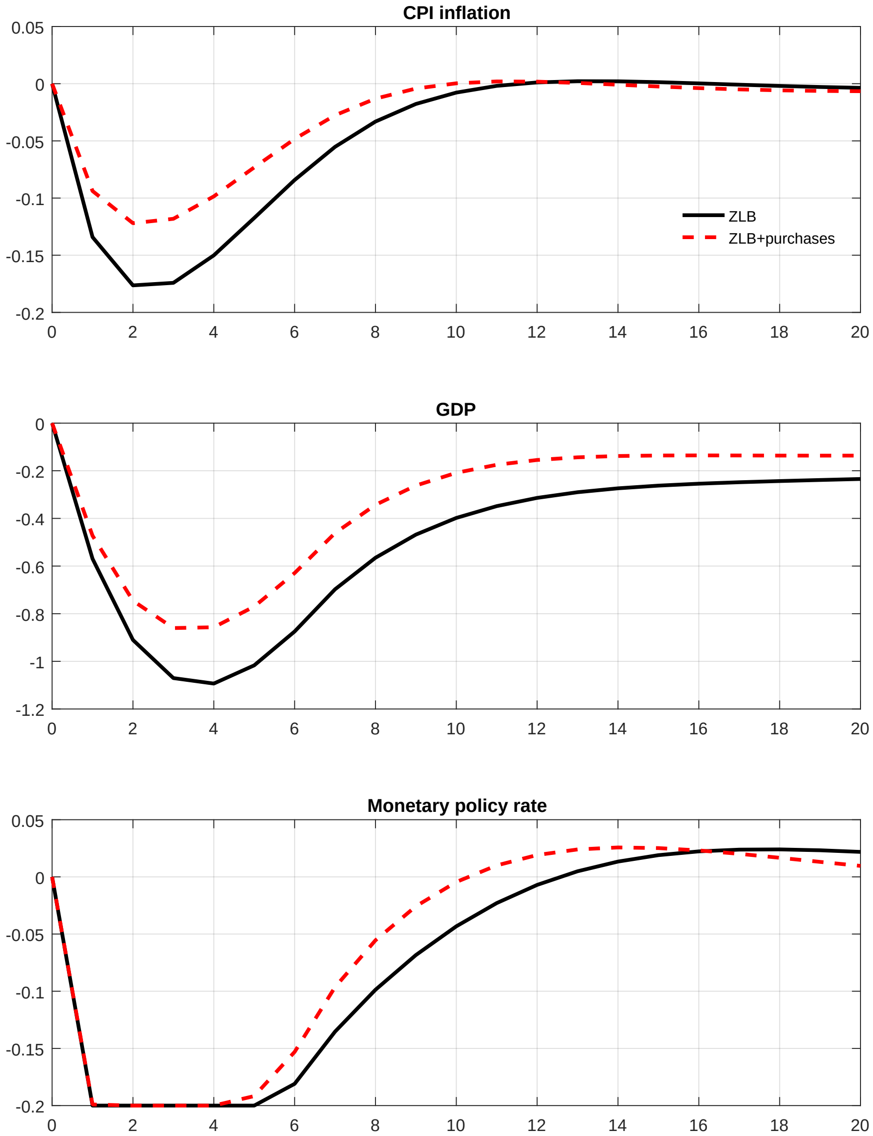
Horizontal axis: quarters; vertical axis: % deviations from baseline.

Figure 5: EA positive term premium shock: EA aggregate demand



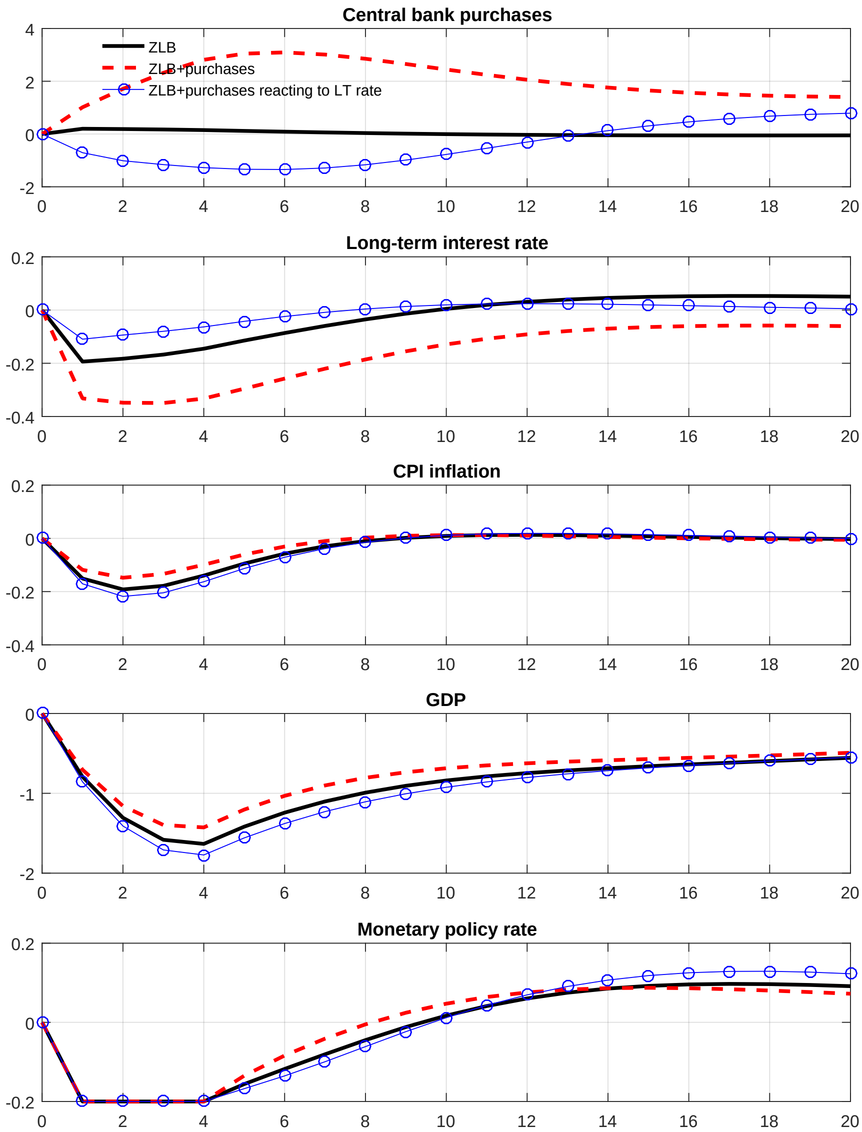
Horizontal axis: quarters; vertical axis: % deviations from baseline.

Figure 6: EA positive term premium shock: EA GDP, inflation, and policy rate



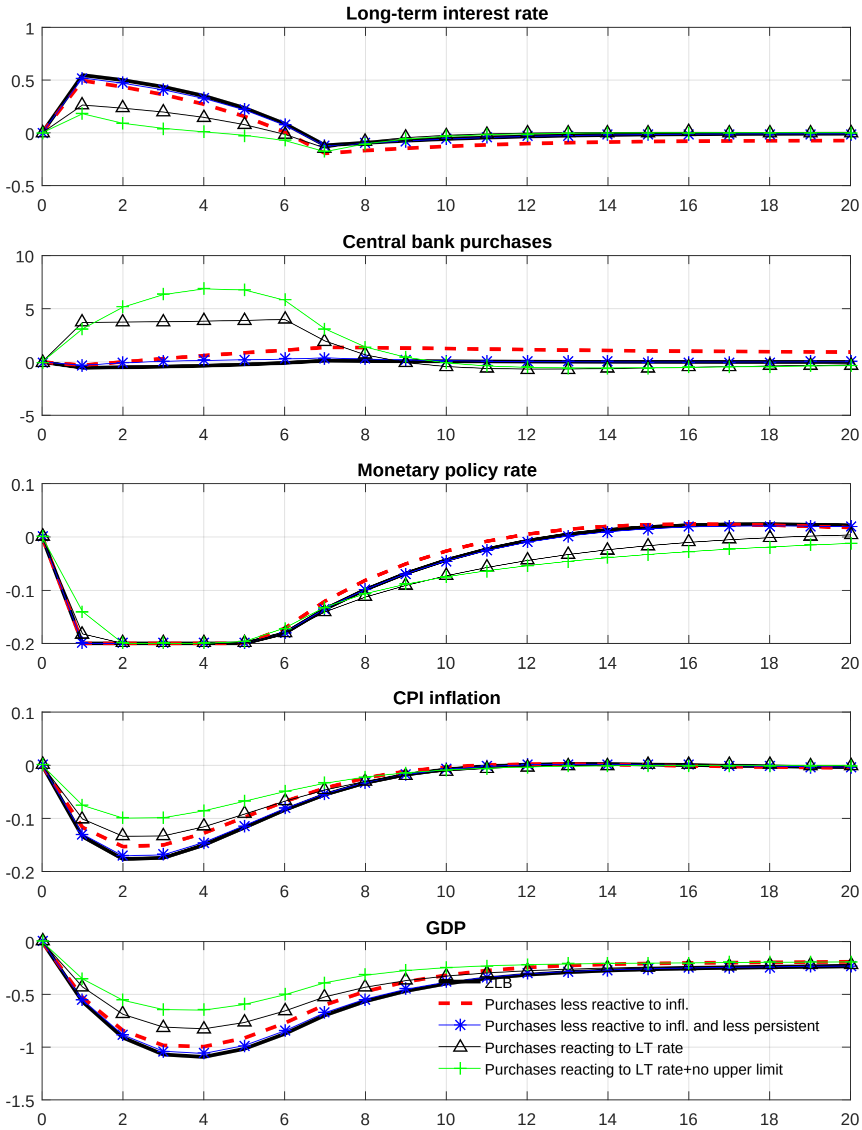
Notes. Horizontal axis: quarters; vertical axis: interest rates and inflation, annualized pp deviations; GDP, % deviations from baseline.

Figure 7: EA negative aggregate demand shock: main EA variables



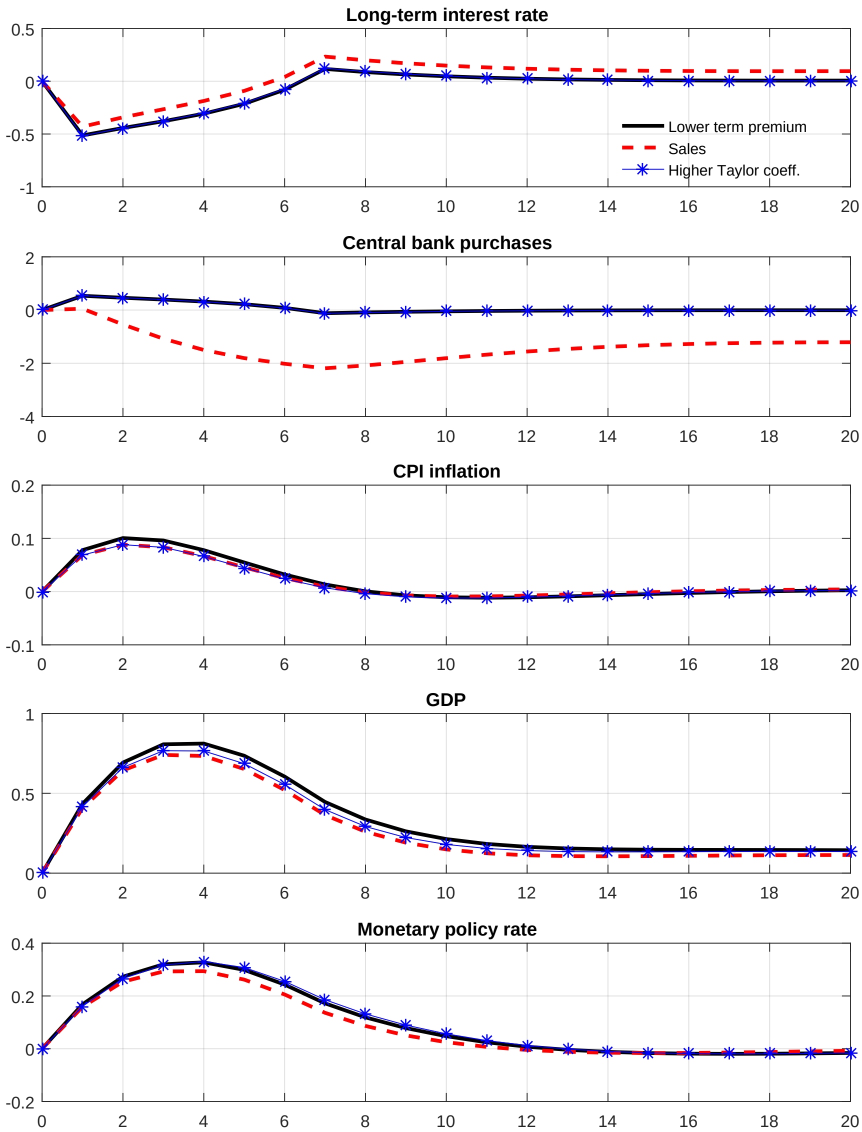
Notes. Horizontal axis: quarters; vertical axis: interest rates and inflation, annualized pp deviations from baseline; purchases, ratio to steady-state annualized GDP, pp deviations from baseline; GDP, % deviations.

Figure 8: EA positive term-premium shock and central bank reaction function: main EA variables



Notes. Horizontal axis: quarters; vertical axis: interest rates and inflation, annualized pp deviations from baseline; purchases, ratio to steady-state annualized GDP, pp deviations from baseline; GDP, % deviations.

Figure 9: EA negative term-premium shock: main EA variables



Notes. Horizontal axis: quarters; vertical axis: interest rates and inflation, annualized pp deviations from baseline; purchases, ratio to steady-state annualized GDP, pp deviations from baseline; GDP, % deviations.