Inflation, financial conditions and non-standard monetary policy in a monetary union. A model-based evaluation

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April 2015

Abstract

This paper evaluates the macroeconomic effects of purchases of long-term sovereign bonds by a central bank in a monetary union when (1) the private sector faces tight financial conditions and (2) the zero lower bound (ZLB) on the policy rate holds. To this end, we calibrate a dynamic general equilibrium model to the euro area (EA). We assume that households in one member country have a large initial debt position and are subject to a borrowing constraint. We simulate the effects of a negative EA-wide demand shock that induces a decline in inflation. The main results are as follows. First, the reduction in inflation amplifies the domestic and cross-country spillovers of the negative demand shock because of the country-specific borrowing constraint and the ZLB. Second, sovereign bond purchases boost economic activity and, hence, indirectly allow households to reduce their debt and relax the borrowing constraint. Third, the new, lower value of debt allows households to smooth consumption, fostering macroeconomic resilience not only in the member country concerned but also in the rest of the monetary union.

Keywords: DSGE models, financial frictions, open-economy macroeconomics, non-standard monetary policy, zero lower bound.
JEL classifications: E43; E44; E52; E58.

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*Bank of Italy. We thank Piergiorgio Alessandri, Ulf Söderström, and participants at the Bank of Italy workshop on "Low inflation and its implications for monetary policy" (March 2015). The opinions expressed are those of the authors and do not reflect views of the Bank of Italy. Any remaining errors are the sole responsibility of the authors. Corresponding author: Alessandro Notarpietro. Economic Research and International Relations Area, Via Nazionale 91, 00184 Rome, Italy. Phone: +39 06 4792 2623, E-Mail: alessandro.notarpietro@bancaditalia.it.

"...[T]he purchases of public securities have a high transmission potential to the real economy. They will further support a broad based easing of financial conditions in the euro area, including those relevant for the borrowing conditions of euro area firms and households."

Mario Draghi, President of the ECB, Introductory statement to the plenary debate of the European Parliament on the ECB's Annual Report 2013. Brussels, 25 February 2015.

1 Introduction

The weakened medium-term outlook for euro-area (EA) inflation and the risks related to a prolonged period of low inflation prompted the adoption of non-standard monetary measures. In January 2015 the European Central Bank has announced the launch of an Expanded Asset Purchase Programme (EAPP), which consists of purchases of private securities and euro-denominated investment-grade securities issued by euro-area governments and institutions in the secondary market.

The announcement of the EAPP has spurred a debate about its macroeconomic effectiveness. A proper assessment of the effects of the program must consider the specific conditions in which the program is being implemented (and to which the program owes its very existence): 1) low and decreasing inflation, 2) short-term policy rate at the zero lower bound (ZLB), and 3) high levels of private debt in some countries of the union.

This paper contributes to the debate by evaluating the macroeconomic effects of long-term sovereign bond purchases by the EA monetary authority, assuming that some households in a EA country are subject to tight borrowing conditions. To this purpose, we simulate a large-scale New Keynesian dynamic general equilibrium model calibrated to the EA and the rest of the world (RW). The EA is formalized as a monetary union of two regions, Home (also referred as "domestic economy") and rest of the euro area (REA), where Home is of medium size (its GDP being around 20 percent of overall EA GDP).

There are two crucial features.

First, while some households (labeled as "indebted") have an initial nominal debt position in both EA regions, only Home households have a large initial debt and are subject to a tight borrowing constraint. The constraint does not allow to further increase borrowing in response to a given shock.

Second, following Chen, Cúrdia, and Ferrero (2012), in each EA country some other households (labeled as "restricted") have access only to long-term sovereign bonds. The purchase of long-term government bonds by the monetary authority, by reducing long-term interest rates, induces restricted households to increase consumption and investment via the standard intertemporal substitution effect. The reduction in the nominal long-term interest rate leads to an increase in inflation expectations, which in turn reinforces the expansionary effect on aggregate demand and contributes to further reduce the real interest rate.

We simulate three scenarios.[1] First, we consider a negative EA-wide demand shock, when both the (EA-wide) ZLB and the Home borrowing constraint are binding. Second, we simulate the launch of the EAPP (we consider only purchases of long-term sovereign bonds). Third, we suppose that the negative demand shock considered in the first scenario hits the EA when the latter lies initially in a (steady-state) equilibrium characterized by the new level of nominal liabilities brought forth by the EAPP. In all scenarios the EA (short-term) monetary policy rate is kept constant at the baseline level for 8 quarters. Thereafter, it follows a standard Taylor rule.

The main results are as follows.

First, as both the ZLB and the Home borrowing constraint are binding, the domestic and cross-country (spillover) effects of the negative demand shock are amplified. In the aftermath of the shock, households subject to the binding constraint cannot smooth consumption by further increasing their borrowing. Thus, falling current and expected inflation rates induce a large drop in the Home aggregate demand, not only through the increase in the real interest rate but also through the binding borrowing constraint. The large drop in the Home aggregate demand is transmitted to the REA through the trade channel. Crucially, the implied reduction in REA bilateral exports contributes to exert downward pressure on REA consumer prices, which is further amplified by the EA-wide ZLB. This

[1] The scenarios are simulated assuming perfect foresight. Households and firms are surprised by the shock in the first period and fully anticipate shocks perturbing the economy in subsequent periods.

results in a relatively large drop in REA economic activity.

Second, the EAPP favors economic activity in both EA regions. The improved economic conditions allow Home indebted households to reduce their debt, thus resulting in Home households' borrowing constraint being relaxed.

Third, given the new lower value of debt, Home indebted households have room to increase debt within the upper bound provided by the borrowing constraint and thus they can smooth consumption in correspondence of the negative demand shock. This makes the Home and, through the cross-country spillovers, the REA economies more resilient.[2]

The paper builds upon several recent contributions. Chen, Cúrdia, and Ferrero (2012) introduce financial segmentation à la Andrés, López-Salido, and Nelson (2004) to evaluate the impact of US quantitative easing. We tailor their set-up to a monetary union framework and consider the role of a country-specific borrowing constraint in propagating the shocks. Previous studies on the US such as, e.g., Gertler and Kiyotaki (2010), Gertler and Karadi (2011), and Cúrdia and Woodford (2011) study the effects of security purchase programs in closed-economy settings. Our exercise is calibrated to the EA and thus features two EA-specific characteristics, that is, the monetary union and open economy dimensions. Moreover, we explicitly devise a crisis situation, where financial markets are structurally segmented, part of the agents face tight borrowing constraints, and the monetary policy lies at the ZLB. Neri and Notarpietro (2014) emphasize the role of ZLB and borrowing constraint for the sign and size of the effects of a given macroeconomic shock. Differently from them, we consider also cross-country spillovers and we focus on the impact of the EAPP.

The paper is organized as follows. Section 2 describes the main features of the model, in particular the assumption of financial market segmentation. Section 3

[2]A caveat applies to the last result. Clearly, the EAPP relies on exceptional and temporary circumstances and the inflation rate has to satisfy the Eurosystem target of price stability. As such, the EAPP cannot be the definitive answer to the issue of reducing large debt positions by improving economic conditions. It should be regarded as a policy measure that can temporarily complement structural, long-run growth-oriented measures which, unavoidably, take some time to be implemented. The latter include a variety of policy measures aimed at expanding the growth potential of the economies, thus making the outstanding amount of private and public debt more sustainable. Gerali, Notarpietro, and Pisani (2014, 2015) evaluate the interaction between ZLB and structural reforms.

reports the main results. Section 4 concludes.

2 The model

We first provide an overview of the model. Subsequently, we illustrate the crucial features for the simulations (borrowing constraint and long-term sovereign bond market). Finally, we report the calibration.

2.1 Overview

The model represents a world economy composed of three regions, that is, Home, REA (Home+REA=EA), and RW. The size of the world economy is normalized to one. Home, REA and RW have sizes equal to n, n^*, and $(1 - n - n^*)$, with $n > 0$, $n^* > 0$, and $n + n^* < 1$.[3] Home and REA share the currency and the monetary authority. The latter sets the nominal interest rate according to EA-wide variables when it is not constrained by the ZLB. The presence of the RW outside the EA allows to assess the role of the nominal exchange rate and extra-EA trade for the transmission of the EAPP.

The crucial features of the model are two.

First, we assume that in both regions some households, labeled as indebted, have an initial nominal debt position and do not have access to sovereign bond markets. However, only in the Home region indebted households have a relatively large initial debt and are subject to borrowing constraints that can become binding. Indebted households allow to formalize (1) potential asymmetric effects of a EA-wide symmetric negative demand shock and (2) amplified cross-country spillovers.

Second, we introduce financial segmentation as in Chen, Cúrdia, and Ferrero (2012), which allows the large-scale asset purchase program to have real effects in our model. In each EA region there are other two types of households distinct from indebted ones, the restricted and the unrestricted. The restricted households have access only to the domestic long-term sovereign bond market and accumulate physical capital. The unrestricted households lend to domestic indebted

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

households, have access to the domestic short- and long-term sovereign bond markets, and trade a riskless private bond with RW households. REA unrestricted and restricted households trade the REA long-term government bond with RW households.[4]

A caveat is necessary at this point. Differently from Chen, Cúrdia, and Ferrero (2012), we want to simulate the impact of the asset purchase program in a situation of severe economic and financial crisis. Hence, we assign the capital accumulation to a segment of the economy (the restricted households) which has limited access to credit markets and arbitrage opportunities. Together with the incidence of the ZLB, this segmentation captures the impaired transmission mechanism of standard monetary policy measures to the real side of the EA economy observed since the onset of the crisis. As restricted households access only the long-term sovereign bonds market, we create a suitable laboratory for the simulation of the EAPP. From a modeling perspective, our estimates of the magnitude of EAPP's effects may be magnified. However, our results fall in the ballpark of estimates of the actual effect of the EAPP reported in other recent contributions.[5]

The remaining features of the model are rather standard and in line with New Keynesian open economy models. Households consume a final good, which is a composite of intermediate nontradable and tradable goods. The latter are domestically produced or imported. Unrestricted households own domestic firms. All households supply differentiated labor services to domestic firms and act as wage setters in monopolistically competitive labor markets by charging a mark-up over their marginal rate of substitution between consumption and leisure.

On the production side, there are perfectly competitive firms that produce two final goods (consumption and investment goods) and monopolistic firms that produce intermediate goods. The two final goods are sold domestically and are produced combining all available intermediate goods using a constant-elasticity-

[4]There is no overlap across household types, as the set $\{\text{indebted}, \text{restricted}, \text{unrestricted}\}$ constitutes a partition of the set of households in each region. The labels for these types of households are mainly for exposition purposes. We simply use the terminology of Chen, Cúrdia, and Ferrero (2012) for unrestricted and restricted households, and use the term "indebted" to refer to a type of household characterized, among other things, by their initial debt position. The assumed financial market structure allows us to have meaningful EA net foreign asset position and trade balance, and the EA QE to affect the EA nominal exchange rate.

[5]See Section 3.2 for a detailed comparison.

of-substitution (CES) production function. The two resulting bundles can have different composition. Intermediate tradable and nontradable goods are produced combining domestic capital and labor, that are assumed to be mobile across sectors. Intermediate tradable goods can be sold domestically and abroad. Because intermediate goods are differentiated, firms have market power and restrict output to create excess profits. We also assume that markets for tradable goods are segmented, so that firms can set a different price for each of the three markets. In line with other dynamic general equilibrium models of the EA (see, among the others, Christoffel, Coenen, and Warne (2008) and Gomes, Jacquinot, and Pisani (2010), we include adjustment costs on real and nominal variables, ensuring that consumption, production, and prices react in a gradual way to a shock. On the real side, habits and quadratic costs prolong the adjustment of households consumption and investment, respectively. On the nominal side, quadratic costs make wages and prices sticky.[6]

In what follows, we report the main new equations for the Home country. Similar equations hold in the REA. Differently from Home and REA, in the RW there exists only one standard representative household. We report other main equations in the Appendix, as they are standard for a New Keynesian model such as ours.

2.2 Indebted households

There exists a continuum of mass $0 \leq \lambda_D \leq 1$ of indebted households. Indebted households' preferences are additively separable in consumption and labor effort. The generic indebted household j receives utility from consumption $C_D(j)$ and disutility from labor $L_D(j)$. Following common practice in the New Keynesian literature, the assumption of cashless economy holds in the model. Her expected lifetime utility is

$$E_0 \left\{ \sum_{t=0}^{\infty} {\beta_D}^t \left[\frac{\left(C_{D,t}\left(j\right) - hC_{D,t-1}\right)^{1-\sigma}}{\left(1-\sigma\right)} - \frac{L_{D,t}\left(j\right)^{1+\tau}}{1+\tau} \right] \right\}, \tag{1}$$

[6] See Rotemberg (1982).

where E_0 denotes the expectation conditional on information set at date 0, β_D is the discount factor ($0 < \beta_D < 1$), $1/\sigma$ is the elasticity of intertemporal substitution ($\sigma > 0$), and $1/\tau$ is the labor Frisch elasticity ($\tau > 0$). The parameter h ($0 < h < 1$) represents external habit formation in consumption.

Indebted households have access only to the market of domestic short-term nominal bonds. They have labor as a unique source of income. The implied budget constraint is

$$\begin{aligned} & B_{D,t}^{S}(j) - B_{D,t-1}^{S}(j) R_{t-1}^{S} \\ = \; & W_{D,t}(j) L_{D,t}(j) \\ & - P_t C_{D,t}(j), \end{aligned} \tag{2}$$

where $B_{D,t}^{S}$ is the (end-of-period) bond that pays the (gross) interest rate R_t^S ($B_{D,t}^{S}$ < 0 is debt). The variable $W_{D,t}(j)$ represents the nominal wage and P_t is the price of the consumption bundle.

Home indebted households are subject to a borrowing constraint:

$$- B_{D,t}^{S}(j) \leq P_t \bar{b}, \tag{3}$$

where $P_t \bar{b} \geq 0$ is the exogenous limit on debt (the borrowing constraint does not hold for REA indebted households).[7]

For simplicity, we assume that indebted households' wage and labor supply are the same as those optimally chosen by the unrestricted households. As such, they maximize their utility only with respect to consumption and debt while they take labor income as given.[8] This assumption may indirectly induce a smaller response of indebted households to negative demand shocks, as financially constrained households would adjust more their labor supply.[9] However, although theoretically appealing a disjoint labor supply choice by indebted households has limited quantitative grip in presence of nominal rigidities. In the our crisis-like

[7] To implement the occasionally binding constraint, we simulate the fully non-linear model under perfect foresight and specify equation (3) using the "max" operator.

[8] As the implied first order conditions are rather standard we do not report them to save on space. They are available upon request.

[9] See, e.g., Guerrieri and Lorenzoni (2011) for the importance of the consumption/labor choice of financially constrained agents.

simulation exercise, the labor income is more likely to be driven by labor demand. Thus, a marginally higher independent labor supply is likely to translate into mild variations in the labor income as opposed to the case of dependent labor supply.

2.3 Restricted households

There exists a continuum of mass $0 \leq \lambda_R \leq 1$ of restricted households. Their preferences are the same as the indebted households' (see (1)). They differ only for the discount factor ($\beta_R \neq \beta_D$). They have access only to the market of long-term sovereign bonds. The latter are formalized as perpetuities (see Woodford 2001), that is, they cost P_t^L at time t and pay a coupon κ^s at time $t+s+1$, where $\kappa \in (0,1]$. The budget constraint is

$$\begin{aligned} & P_t^L B_{R,t}^L(j) - \sum_{s=1}^{\infty} \kappa^{s-1} B_{R,t-s}^L(j) \\ = \; & R_t^K K_{t-1}(j) + W_{R,t}(j) L_{R,t}(j) \\ & - P_t C_{R,t}(j) - P_t^I I_t(j) - AC_{R,t}^W(j), \end{aligned} \tag{4}$$

where $B_{R,t}^L$ is the amount of long-term sovereign bonds. Households rent existing physical capital stock $K_{t-1}(j)$ to domestic firms at the nominal rate R_t^K. The variable P_I is the price of the investment bundle I.[10]

The law of motion of capital accumulation is

$$K_t(j) = (1-\delta) K_{t-1}(j) + \left(1 - AC_t^I(j)\right) I_t(j), \tag{5}$$

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

$$AC_t^I(j) \equiv \frac{\phi_I}{2} \left(\frac{I_t(j)}{I_{t-1}(j)} - 1 \right)^2, \text{ with } \phi_I > 0. \tag{6}$$

Finally, households act as wage setters in a monopolistic competitive labor market. Each household j supplies one particular type of labor services, which is an imperfect substitute to services supplied by other households. It sets its nominal

[10] As for the consumption basket, the investment bundle is a composite of tradable and non-tradable goods. The composition of consumption and investment goods can be different.

wage taking into account labor demand and quadratic adjustment costs $AC^W_{R,t}$ à la Rotemberg on the nominal wage $W_{R,t}(j)$:[11]

$$AC^W_{R,t}(j) \equiv \frac{\kappa_W}{2}\left(\frac{W_{R,t}(j)/W_{R,t-1}(j)}{\Pi^{\alpha_W}_{WR,t-1}\bar{\Pi}^{1-\alpha_W}_{EA}} - 1\right)^2 W_{R,t}L_{R,t}, \text{ with } \kappa_W > 0, \tag{7}$$

where $\kappa_W > 0$ and $0 \leq \alpha_W \leq 1$ are parameters, the variable $\Pi_{WR,t} \equiv W_{R,t}/W_{R,t-1}$ is the wage inflation rate, and $\bar{\Pi}_{EA}$ is the long-run inflation target of the EA monetary authority (assumed to be constant). The adjustment costs are proportional to the per-capita wage bill of restricted households, $W_{R,t}L_{R,t}$.[12]

Restricted households are crucial for the EAPP to have real effects in our model. As they cannot make arbitrage between short-term and long-term bonds, their consumption and saving decisions depend only upon the long-term interest rate. Therefore, the monetary policy authority can affect their consumption, investment, and labor decisions also by directly intervening in the long-term sovereign bond market to change the long-term interest rate.

2.4 Unrestricted households

There exists a continuum of mass $0 \leq 1 - \lambda_R - \lambda_D \leq 1$ of unrestricted households. These households have the same preferences as indebted households (see (1)), including for their discount factor ($\beta_U = \beta_D$).

Unrestricted households have access to multiple financial assets: short-term private bonds (B^S_U, exchanged with domestic indebted households), short-term sovereign bonds (B^G, exchanged with the domestic government), and long-term sovereign bonds (B^L_U, exchanged with the domestic restricted households and, for the case of the REA, with the RW households). Thus, they have several opportunities to smooth consumption when facing a shock. Their budget constraint

[11] See Rotemberg (1982).

[12] As the implied first order conditions are rather standard we do not report them to save on space. They are available upon request.

is

$$
\begin{aligned}
& P_t^L B_{U,t}^L(j) - \sum_{s=1}^{\infty} \kappa^{s-1} B_{U,t-s}^L(j) \\
& + B_{U,t}^S(j) - B_{U,t-1}^S(j) R_{t-1}^S \\
& + B_t^G(j) - B_{t-1}^G(j) R_{t-1} \\
= \; & W_{U,t}(j) L_{U,t}(j) - P_t C_{U,t}(j) \\
& + Tr_{U,t}(j) - AC_{U,t}^W(j) - AC_{U,t}^B(j) + \Pi_t^P(j),
\end{aligned} \tag{8}
$$

where the short-term government bond B_t^G pays the EA monetary policy rate R_t. The unrestricted households face adjustment costs $AC_{U,t}^B$ on all bond holdings. The presence of adjustment costs guarantees that the bond holdings follow a stationary process and that the economy converges asymptotically to the steady state.[13] First order conditions imply no-arbitrage conditions for the unrestricted households.[14] Thus, in equilibrium the interest rates paid by the different bonds are equal to the monetary policy rate R_t, except for the spreads induced by the longer maturity and the adjustment costs.[15] Unrestricted households own all domestic firms, and $\Pi_t^P(j)$ stands for dividends from ownership of domestic monopolistic firms. Claims to firms' profits are not internationally tradable.

[13] We assume a standard quadratic form for the adjustment costs, that is,

$$AC_{U,t}^B(j) \equiv \frac{\phi_B}{2}\left(P_t^L B_{U,t}^L(j) - \bar{P}^L \bar{B}_U^L\right)^2 + \frac{\phi_B}{2}\left(B_{U,t}^S(j) - \bar{B}_U^S\right)^2 + \frac{\phi_B}{2}\left(B_t^G(j) - \bar{B}^G\right)^2, \text{ with } \phi_B > 0,$$

where $\bar{P}^L \bar{B}_U^L$, $\bar{B}_U^S$ and $\bar{B}^G$ are the (symmetric) steady-state values of the long-term sovereign bond, short-term private bond, and short-term sovereign bond holdings. We set ϕ_B to a value low enough not to impact the dynamics and yet maintain the stationarity of the model.

[14] As the implied first order conditions are rather standard we do not report them to save on space. They are available upon request.

[15] See Chen, Cúrdia, and Ferrero (2012) for the details. Our calibration implies that households can modify their financial positions without facing relevant adjustment costs.

2.5 Monetary policy

The EA monetary policy rate is either stuck at the ZLB or controlled by the EA monetary authority according to a standard Taylor rule. Hence,

$$\left(\frac{R_t}{\bar{R}}\right) = \max\left(1, \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\frac{\Pi_{EA,t}}{\bar{\Pi}_{EA}}\right)^{(1-\rho_R)\rho_\pi} \left(\frac{GDP_{EA,t}}{GDP_{EA,t-1}}\right)^{(1-\rho_R)\rho_{GDP}}\right), \quad (9)$$

where R_t is the (gross) monetary policy rate. The parameter ρ_R ($0 < \rho_R < 1$) captures inertia in interest rate setting, while the parameter $\bar{R}$ represents the steady state gross nominal policy rate. The parameters ρ_π and ρ_{GDP} are respectively the weights of EA consumer price index (CPI) inflation rate ($\Pi_{EA,t}$) (taken as a deviation from its long-run constant target $\bar{\Pi}_{EA}$) and GDP ($GDP_{EA,t}$).[16] When the policy rate exits from the ZLB, it reverts to the Taylor rule.[17]

Finally, the EA monetary authority can adopt non-standard monetary policy measures in the form of Home and REA long-term sovereign bonds' purchases, which amount to $B^L_{EAPP,t}$ and $B^{L*}_{EAPP,t}$, respectively.

[16]The CPI inflation rate is a geometric average of Home and REA CPI inflation rates (respectively Π_t and Π^*_t) with weights equal to the correspondent country size (as a share of the EA GDP), that is,

$$\Pi_{EA,t} \equiv (\Pi_t)^{\frac{n}{n+n^*}} (\Pi^*_t)^{\frac{n^*}{n+n^*}} . \quad (10)$$

The EA GDP, $GDP_{EA,t}$, is the sum of Home and REA GDPs (respectively GDP_t and GDP^*_t), that is,

$$GDP_{EA,t} \equiv GDP_t + GDP^*_t . \quad (11)$$

The definition of nominal GDP_t is:

$$GDP_t = P_t C_t + P^I_t I_t + P_{N,t} C^g_t + P^{EXP}_t EXP_t - P^{IMP}_t IMP_t \quad (12)$$

where P_t, P^I_t, P^{EXP}_t, and P^{IMP}_t are prices of consumption, investment, exports, and imports, respectively.

[17]As in the case of the borrowing constraint, we implement the ZLB by simulating the fully non-linear model under perfect foresight and specify equation (9) using the "max" operator.

2.6 Fiscal authority

Fiscal policy is set at the regional level. The government budget constraint is

$$\begin{aligned} & B_{g,t}^{S} - B_{g,t-1}^{S} R_{t-1} + P_t^L B_{g,t}^L - (1 + \kappa P_t^L) B_{g,t-1}^L \\ = \; & P_{N,t} C_t^g - TAX_t, \end{aligned} \tag{13}$$

where $B_{g,t}^S \geq 0$ and $B_{g,t}^L \geq 0$ are respectively the short- and long-term nominal sovereign debt. The variable C_t^g represents government purchases of goods and services, $TAX_t > 0$ are lump-sum taxes to households. Consistent with the empirical evidence, C_t^g is fully biased towards the intermediate nontradable good. Hence it is multiplied by the corresponding price index $P_{N,t}$.[18]

The government follows a fiscal rule defined on lump-sum taxes. This rule aims at bringing the short-term public debt, as a percentage $b_g^S > 0$ of domestic GDP, in line with its target $\bar{b}_g^S$ and at limiting its increase $(b_{g,t}^S / b_{g,t-1}^S)$:

$$\frac{TAX_t}{TAX_{t-1}} = \left(\frac{b_{g,t}^S}{\bar{b}_g^S} \right)^{\phi_1} \left(\frac{b_{g,t}^S}{b_{g,t-1}^S} \right)^{\phi_2}, \tag{14}$$

where parameters $\phi_1, \phi_2 > 0$ call for an increase in lump-sum taxes whenever the short-term debt level is above target and for a larger increase whenever its dynamics is not converging. A similar rule holds in the REA. We include only the short-term debt in the fiscal rule for two reasons. First, we hold the supply of long-term government bonds fixed so as to isolate the direct demand effects of the EAPP. Second, we need the fiscal rule to stabilize the short-term debt and, given that the long-term component is exogenous, the overall public debt.[19] In the RW, as there is no distinction between short- and long-term domestic sovereign bonds, the rule holds for the overall public debt.

We assume that the long-term sovereign bond $B_{g,t}^L$ is kept constant at its steady-state level, so that changes in the long-term interest rate are entirely due to the non-standard monetary policy measures. Finally, lump-sum taxes are paid by

[18] See Corsetti and Müller (2006).

[19] We take into account this distinction when we calibrate the model and more specifically the fiscal target $\bar{b}_g^S$, as reported in Table 5.

unrestricted households only. In this way we are able to isolate the response of restricted and indebted households to the EAPP from the indirect fiscal adjustments implied by the program. However, as the Ricardian equivalence does not hold because restricted households hold long-term sovereign bonds but are not subject to lump-sum taxes, our assumption on the distribution of lump-sum taxes or, equivalently, on the initial distribution of public debt implies that sovereign bond holdings are net wealth. We perform sensitivity analysis on the initial sovereign bond holdings in Section 3.4.1.

2.7 Bonds market clearing conditions

The Home short-term bond is traded only domestically between indebted and unrestricted households:

$$\int_0^{n\lambda_D} B^S_{D,t}(j)dj + \int_{n(\lambda_D+\lambda_R)}^{n} B^S_{U,t}(j)dj = 0. \tag{15}$$

The market clearing condition for the Home long-term government bond is

$$\int_{n\lambda_D}^{n(\lambda_D+\lambda_R)} B^L_{R,t}(j)dj + \int_{n(\lambda_D+\lambda_R)}^{n} B^L_{U,t}(j)dj + B^L_{EAPP,t} = B^L_{g,t}, \tag{16}$$

where the variable $B^L_{EAPP,t}$ represents the demand for long-term sovereign bonds by the EA monetary authority (see Section 2.5). The market clearing condition for the REA long-term government bond is

$$\int_{n^*\lambda^*_D}^{n^*(\lambda^*_D+\lambda^*_R)} B^L_{R,t}(j^*)dj^* + \int_{n^*(\lambda^*_D+\lambda^*_R)}^{n^*} B^L_{U,t}(j^*)dj^* + \int_{n^*}^{1} B^L_t\left(j^{**}\right)dj^{**} + B^{L*}_{EAPP,t} = B^{L*}_{g,t}, \tag{17}$$

where the variables $B^L_{R,t}(j^*)$, $B^L_{U,t}(j^*)$, $B_t\left(j^{**}\right)$, and $B^{L*}_{EAPP,t}$ represent the demand for REA long-term sovereign bonds by the REA restricted household, REA unrestricted household, RW household, and EA monetary authority, respectively.

The market clearing for the Home short-term sovereign bond is

$$\int_{n(\lambda_D+\lambda_R)}^{n} B^G_t(j)dj = B^S_{g,t}, \tag{18}$$

as the short-term sovereign bond is held only by unrestricted households. Similar equations hold in the REA.

2.8 Equilibrium

In each country initial asset positions, preferences, and budget constraints are the same for households belonging to the same type and firms belonging to the same sector. Moreover, profits from ownership of domestic firms are equally shared between unrestricted households. Thus, we consider the representative household for each household type (indebted, restricted, and unrestricted). Moreover, we consider the representative firm for each sector (final nontradable, intermediate tradable, and intermediate nontradable). The implied symmetric equilibrium is a sequence of allocations and prices such that, given initial conditions and considered shocks, households and firms satisfy their corresponding first order conditions and market clearing conditions hold.

2.9 Calibration

The model is calibrated at quarterly frequency. We set some parameter values so that steady-state ratios are consistent with average euro-area 2014 national account data, which are the most recent and complete available data. For remaining parameters we resort to previous studies and estimates available in the literature.[20]

Table 1 contains parameters for preferences and technology. Parameters with "$*$" and "$**$" are related to the REA and the RW, respectively. We assume perfect symmetry between the REA and the RW unless differently specified. The discount factor of EA unrestricted households is set to 0.9927, so that the steady-state short-term interest rate is equal to 3.0 per cent on an annual basis. Discount factors of EA indebted households and RW households are also set to 0.9927. The discount factor of restricted households determines the steady-state value of the long-term interest rate and is set to 0.99, so that in steady state the spread between short- and long-term bond is equal to 1.1 percentage points. In each EA region the share of restricted households is set to 0.35 and the share of indebted households to 0.2.

[20]See the New Area Wide Model (NAWM, Christoffel, Coenen, and Warne (2008) and Euro Area and Global Economy Model (EAGLE, Gomes, Jacquinot, and Pisani (2010)

The value for the intertemporal elasticity of substitution, $1/\sigma$, is 1. The Frisch labor elasticity is set to 0.5. Habit is set to 0.6. The depreciation rate of capital is set to 0.025.

In the production functions of tradables and nontradables, the elasticity of substitution between labor and capital is set to 0.93. To match investment-to-GDP ratios, the bias towards capital in the production function of tradables is set to 0.56 in Home and, in the REA and in the RW, to 0.46. The corresponding value in the production function of nontradables is set to 0.53 in Home and 0.43 in the REA and RW. In the final consumption and investment goods the elasticity of substitution between domestic and imported tradable is set to 1.5, while the elasticity of substitution between tradables and nontradables is set to 0.5, as empirical evidence suggests that it is harder to substitute tradables for nontradables than to substitute across tradables. The biases towards the domestically produced good and composite tradable good are chosen to match the Home and REA import-to-GDP ratios. In the consumption bundle the bias towards the domestic tradable is 0.68 in Home, 0.59 in the REA, and 0.90 in the RW. The bias towards the composite tradable is set to 0.68 in Home and to 0.50 in the REA and the RW. For the investment basket, the bias towards the domestic tradable is 0.50 in Home, 0.49 in the REA, and 0.90 in the RW. The bias towards the composite tradable is 0.78 in Home and 0.70 in the REA and in the RW.

Table 2 reports gross mark-up values. In the Home tradable and nontradable sectors and in the Home labor market the mark-up is set to 1.08, 1.29, and 1.60, respectively (the corresponding elasticities of substitution across varieties are set to 13.32, 4.44, and 2.65). In the REA tradable and nontradable sectors and in the REA labor market the gross mark-ups are respectively set to 1.11, 1.24, and 1.33 (the corresponding elasticities are set to 10.15, 5.19, and 4.00). Similar values are chosen for the corresponding parameters in the RW.

Table 3 contains parameters that regulate the dynamics. Adjustment costs on investment change are set to 6. Nominal wage quadratic adjustment costs are set to 200. In the tradable sector, we set the nominal adjustment cost parameter to 300 for Home tradable goods sold domestically and in the REA; for Home goods sold in the RW, the corresponding parameter is set to 50. The same parameterization is adopted for the REA, while for the RW we set the adjustment cost on goods exported to Home and the REA to 50. Nominal price adjustment costs are set to 500 in the nontradable sector. The parameter regulating the adjustment costs paid by the unrestricted household on deviations of bond positions from steady-state levels is set to 0.00055. In this way, adjustment costs do not greatly affect the model dynamics and yet help to stabilize them.

Table 4 reports the parametrization of the systematic feedback rules followed by the fiscal and monetary authorities. In the fiscal policy rule (14) we set $\phi_1 = 0.05$ and $\phi_2 = 1.01$ for Home, and $\phi_1 = \phi_2 = 1.01$ for the REA and the RW. It is always lump-sum transfers to adjust. The central bank of the EA targets the contemporaneous EA-wide consumer price inflation (the corresponding parameter is set to 1.7) and the output growth (the parameter is set to 0.1). Interest rate is set in an inertial way and hence 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.

Table 5 reports the great ratios, which are matched by the model steady state under our baseline calibration. We assume a zero steady-state net foreign asset position of each region. The sizes of Home and REA GDPs as shares of world GDP are set to 5 percent and to 17 percent, respectively. So the Home GDP is around 20 percent of EA GDP.

Indebted households' debt-to-yearly GDP is set to 85 percent for the Home country and to 55 percent for REA. Short-term public debt (ratio to yearly GDP) is set to 13 percent for Home and 8 for the REA. Long-term public debt is set to 115 and 90 percent of GDP for Home and the REA. We assume that in each country long-term sovereign bond holdings are equally shared between unrestricted and restricted households. We perform sensitivity analysis on these initial holdings.

Variables of the RW are set to values equal to those of corresponding REA variables.

3 Results

We initially show the effects of a recessionary demand shock that drives inflation down when the EA monetary policy rate is at its baseline level for 8 quarters and the borrowing constraint (3) is binding in the Home country. Subsequently, we show the effects of the EAPP on the main macroeconomic variables and on the borrowing position of the indebted households. We then show the response of the main macroeconomic variables to the same recessionary demand shock as in the first simulation, under the assumption that the EA economy lies initially in a (steady-state) equilibrium characterized by the new level of indebted households' borrowing position brought forth by the EAPP. Finally, we report some sensitivity analyses on the effects of the EAPP.

3.1 Negative demand shock with binding borrowing constraint

We implement a sequence of negative preference and investment-specific technology shocks, lasting for 8 quarters. The shocks simultaneously and symmetrically affect both EA regions. All shocks but the initial one are fully anticipated by households and are calibrated to induce a drop in EA inflation rate approximately equal to 0.15 (annualized) percentage points in the first year. Consistently with the current EA monetary conditions, the short-term monetary policy rate is assumed to be stuck at the ZLB (for 8 quarters).[21]

Figure 1 reports the results. As expected, the negative demand shock has recessionary effects in both regions. GDP, consumption, and investment drop. The reason is the increase in the real interest rate, due to the ZLB and the persistent reduction in inflation. The lower aggregate demand induces a drop in labor and real wages (not reported).

The drop in economic activity is larger in the Home country than in the REA. As shown in Figure 2, Home indebted households largely reduce their consumption because of the presence of the borrowing constraint being binding in the Home country but not in the REA: Home indebted households face a drop in their wage income, associated with the the drop in employment, and would borrow more from domestic unrestricted households to smooth consumption, but they cannot do it. There is a negative wealth effect, amplified by the constraint. To illustrate

[21]The purpose of this exercise is merely illustrative. We calibrate the shock so as to achieve a decrease in the inflation rate that would still maintain the short-term monetary policy rate at the ZLB for the following 8 quarters.

the intuition, let us consider the log-linearized budget constraint of the indebted households, which is

$$\bar{c}_{D,t}\hat{c}_{D,t} = \bar{w}_D\bar{L}_D\left(\hat{w}_{D,t} + \hat{L}_{D,t}\right) - \bar{b}_D^S\hat{b}_{D,t}^S + \bar{b}_D^S\left(\hat{b}_{D,t-1}^S - \hat{\pi}_t + \hat{r}_{S,t}\right), \quad t = 0, 1, 2, \cdots, \tag{19}$$

where the symbols "$^-$" and "$^\wedge$" denote the steady-state and log-deviation (from steady state) value of a given variable, respectively. Variables c_D, w_D, L_D, b_D^S, π, and r_S represent consumption, real wage, labor, real debt, (net) inflation, and (net) nominal interest rate, respectively (real wage and real debt are equal to the corresponding nominal variables divided by the consumer price level). Home households cannot increase $\hat{b}_D^S$ to smooth consumption because of the binding borrowing constraint ($\hat{b}_D^S = 0$), and the short-term nominal interest rate is constant at its baseline level ($\hat{r}_{S,t} = 0$). The previous equation can be rewritten for Home indebted households as

$$\bar{c}_D\hat{c}_{D,t} = \bar{w}_D\bar{L}_D\left(\hat{w}_{Dt} + \hat{L}_{D,t}\right) - \bar{b}_D^S\hat{\pi}_t, \quad t = 0, 1, 2, \cdots, \tag{20}$$

which shows the key role of inflation in determining consumption decisions.

Inflation affects the budget constraint through the term $\bar{b}_D^S\hat{\pi}_t$. *Ceteris paribus*, the larger the initial (steady-state) debt ($\bar{b}_D^S < 0$), the larger the negative impact of lower inflation on consumption. The outstanding (initial) debt increases in real terms because of the drop in consumer prices. The implied negative wealth effect adds to the negative intertemporal substitution effect associated with the high real interest rate. Indebted households have to reduce their consumption more than unrestricted and restricted households. The latter two households have better consumption smoothing opportunities than indebted households', because they are not subject to borrowing constraints and, for unrestricted households, have access to several financial markets.[22]

[22]Moreover, their initial financial positions (on sovereign markets and, for unrestricted households, on domestic short-term bonds market) are positive. As such, the decrease in inflation has a positive wealth effect on their demands for goods and services, that partially counterbalances the negative substitution effect associated with the increase in the real interest rate.

3.2 The EAPP

The EAPP is formalized as an exogenous increase in the purchases of Home and REA long-term sovereign bonds by the EA monetary authority, respectively $B^{L}_{EAPP,t}$ and $B^{L*}_{EAPP,t}$ (see equation (16)). The shock is calibrated so that it corresponds to overall monthly purchases of 60 billion euros that last from March 2015 to the end of September 2016 (seven quarters). In our simulations, Home and REA long-term sovereign bond purchases are proportional to the size of the corresponding region (measured as a share of EA GDP). The phasing out is assumed to be gradual over 2 years. The short-term monetary policy rate is assumed to be constant for 8 quarters, reflecting the commitment of the central bank to maintain an accommodative stance for a prolonged period (this being the case, in this experiment the constant monetary policy rate is not due to the ZLB constraint, but should be interpreted as a deliberate policy choice).

Figure 3 shows the results. Economic activity and the inflation rate increase in both EA regions. The effects are rather symmetric across the two regions. Inflation gradually increases and achieves a peak of around 0.5 annualized percentage points after two quarters. Thereafter, it gradually decreases and returns to its baseline level after 12 periods. GDP increases by around 0.5% on average in the first year and follows a similar path back to the initial level.

Home and REA consumption and investment benefit from the reduction in the real long-term interest rate. The latter decreases because of the decline in the current and expected nominal long-term interest rate and the increase in the current and expected inflation rates. Consistently with the rise in production, labor effort and real wages (not reported) increase.

As reported in Figure 4, indebted households optimally choose to increase their consumption, benefiting from the increase in wage income associated with higher employment and, because of the increase in inflation, from the reduction in the initial level of debt in real terms. As shown by the log-linearized budget constraint (see equation (19)), the lower real value of outstanding debt has a positive wealth effect on indebted households.[23]

[23] To the opposite, unrestricted households have a deterioration in their initial wealth in real terms. Differently from indebted households, they have access to multiple assets and hence they can better smooth consumption when facing the shock and the related implied wealth effect.

There is also a positive intertemporal substitution effect on consumption associated with the lower short-term real interest rate that positively affects all types of households. The real interest rate decreases because inflation increases while the monetary policy rate is kept constant at the baseline level by the monetary authority.

Finally, indebted households reduce their debt thanks to the improvement in macroeconomic conditions induced by the EAPP. In the case of Home indebted households, the debt reduction makes the borrowing constraint not binding (at least temporarily, given the temporary nature of the EAPP).

Our simulation of the EAPP's effects is similar to estimates on the effects of other large-scale asset purchase programs. Concerning the effects on long-term interest rates, Chen, Cúrdia, and Ferrero (2012) report that a USD100 billion-worth asset purchase program would reduce the 10-year Treasury yield by 3 bp to 15 bp.[24] Rescaling accordingly our exercise, the simulation yields a drop of 7 bp for the REA and 5 bp for the Home country, which is consistent with previous estimates.[25] Recent estimates for the EA in occasion of the EAPP hover around −5 bp.[26] The estimated effects on GDP and inflation are more heterogeneous and reflect the differences in methods, modelling choices, and calibrations of the asset purchases. Chen, Cúrdia, and Ferrero (2012) simulate a large-scale asset purchase program of around USD600 billion (around 42% of the overall size of the EAPP) and obtain annualized increases of 0.13 percentage points (pp) in GDP growth and 0.03 pp in inflation. Assuming a similar size for the EAPP, we would obtain annualized increases of around 0.21 pp in both GDP growth and inflation. These differences are mainly due to the greater response of investment, whose role is crucial in our crisis experiment with financial segmentation, and the longer incidence of the ZLB (8 quarters instead of 4), which magnifies the impact of the decrease in long-term interest rates.

[24]See for reference Bomfim and Meyer (2010), Doh (2010), Gagnon, Raskin, Remache, and Sack (2011), Swanson (2011), Krishnamurthy and Vissing-Jorgensen (2011), D'Amico, English, López-Salido, and Nelson (2012), Hamilton and Wu (2012), D'Amico and King (2013), and Neely (2015).

[25]Considering the bilateral EUR/USD exchange rate on November 5, 2014, USD100 billion correspond to around EUR80 billion, which represent roughly 7% of the EUR1140 billion of the EAPP.

[26]See Bank of Italy's Economic Bulletin, April 2015.

3.3 Negative demand shock when the borrowing constraint is not binding

Figure 5 reports the macroeconomic effects of a negative demand shock that hits the EA economy when Home indebted households have a level of initial debt equal to the minimum level achieved because of the EAPP. More importantly, the new starting level is lower than the one in Section 3.1, which corresponded to the borrowing limit dictated by the borrowing constraint. Thus, in this new simulation the borrowing constraint is not binding. The negative demand shock is the same as the one described in Section 3.1. As in previous simulations, the ZLB is assumed to be binding. For comparison, the figure reports also the results for the case when the Home borrowing constraint is binding in correspondence of the new lower debt level ($\bar{b}$ in equation 3). Even if the shock is the same and the ZLB holds in both scenarios, the responses are different. Home GDP decreases more when the Home borrowing constraint is binding because of the larger decrease in aggregate consumption, which in turn mainly reflects the behavior of indebted households. Similarly, the REA GDP decreases relatively more when the Home borrowing constraint is binding. As shown in Figure 6, the responses of Home indebted households, and in particular their consumption and borrowing, are crucial for explaining the differences across the two scenarios. The binding borrowing constraint amplifies Home spillovers to the REA through two channels. The first one is the conventional trade channel. A large drop in Home aggregate demand implies a large drop in imports from the REA. The second is the low inflation channel associated with the ZLB. Lower demand by the Home region induces a decline in REA inflation through lower imports. As the EA monetary policy rate is constrained, the decline in REA inflation implies an increase in REA real interest rate. The latter contributes to amplify the spillover to the REA economy.

Several caveats apply to the reported results. First, the EAPP is a necessarily temporary measure that per se does not lead to a permanent improvement in the borrowing position of indebted households, although it can help relax the financial constraints for some time, mainly through its effect on inflation, real interest rates, and, hence, improved general economic conditions. Second, we are assuming that the size of the (negative demand) shock is not large enough to generate an increase in debt that leads the households to hit the borrowing limit once again. In this respect, the EAPP can be thought of as a useful temporary measure, to be put in place jointly with other permanent, structural measures which are instead characterized by a more gradual implementation and are aimed at permanently moving the economy towards a more sustainable financial path.

Overall, the comparison of the simulations shows that a EA-wide negative demand shock can be amplified by a country-specific binding borrowing constraint, with negative implications not only for the country itself but also for the REA. By relaxing the constraint, the EAPP favors the resilience to a negative demand shock not only of the specific region, but of the whole EA.

3.4 Sensitivity analysis

We perform sensitivity analysis with respect to (1) the initial positions in sovereign bonds of restricted and unrestricted households and (2) the gradualness of the phasing out of the EAPP.

3.4.1 Initial position on long-term sovereign bonds

In the benchmark simulation we make the neutral assumption that in each region the restricted and unrestricted households hold the same (initial) steady-state amount of sovereign bonds (50 percent of domestic sovereign bonds supply, as it is assumed that the central bank does not hold sovereign bonds in steady state). We now assume that households' initial sovereign bonds shares are different. Specifically, unrestricted households initially hold 75 percent of long-term bonds (and restricted households hold the remaining 25 percent).

Figure 7 reports the results. The increase in GDP is now larger than in the benchmark simulation. Restricted households have an initial nominal amount of long-term bonds which is lower than in the benchmark case. As such, the negative wealth effect associated with the increase in inflation is now lower. Restricted households increase their demand for consumption and investment in physical capital relatively more (not reported), favoring a larger expansion of economic activity.

3.4.2 Gradual phasing-out

We now assume that the phasing out of the EAPP lasts two and a half years, as opposed to two years in the benchmark scenario. Figure 8 reports the results. The effects of the EAPP are now larger. All households benefit from low long-term interest rates for a longer amount of time. Restricted households have an incentive to further increase investment in physical capital. Other households further increase their consumption. GDP and inflation increase more than in the benchmark scenario.

4 Conclusions

This paper evaluates the macroeconomic effects of EA's EAPP with a particular focus on the asset position of households. The EAPP favors inflation and economic activity and, hence, can contribute to reduce the value of households' debt in real terms. This is even more important in the economic context that currently characterizes the euro area, where the short-term policy rate is at the ZLB and current and expected inflation rates are much lower than the medium-term price stability target of the Eurosystem.

Clearly, the EAPP is a proper policy response only in exceptional circumstances. Moreover, it can only be a temporary measure. In the EA, an asset purchase program is further constrained by the need to satisfy the Eurosystem target for price stability. As such, the EAPP cannot be the definitive answer to the issue of reducing large debt positions by improving economic conditions. It should be regarded as a policy measure that can temporarily complement structural, long-run growth-oriented measures which, unavoidably, take some time to be implemented. The latter include a variety of policy measures aimed at expanding the growth potential of the economies, thus making the outstanding amount of private and public debt more sustainable.

Reported results rise new questions. We have considered only nominal bonds and nominal debt. Households' and firms' portfolios include more assets and liabilities, that differ in terms of their degree of liquidity and risk. A richer optimal portfolio problem can better characterize the impact of inflation and interest rates on wealth and, hence, on aggregate demand. We leave these issues for future research.

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Tables and Figures

Table 1: Parametrization

Parameter	H	REA	RW
Discount factor $\beta_U, \beta_U^*, \beta^{**}$	0.9927	0.9927	0.9927
Discount factor β_R, β_R^*	0.99	0.99	–
Discount factor β_D, β_D^*	0.9927	0.9927	–
Intertemporal elasticity of substitution $1/\sigma$	1.0	1.0	1.0
Share of restricted households λ_R	0.35	0.35	–
Share of indebted households λ_D	0.20	0.20	–
Inverse of Frisch Elasticity of Labor Supply τ	2.0	2.0	2.0
Habit h	0.6	0.6	0.6
Depreciation rate of capital δ	0.025	0.025	0.025
Tradable Intermediate Goods			
Substitution between factors of production $\xi_T, \xi_T^*, \xi_T^{**}$	0.93	0.93	0.93
Bias towards capital $\alpha_T, \alpha_T^*, \alpha_T^{**}$	0.56	0.46	0.46
Non tradable Intermediate Goods			
Substitution between factors of production $\xi_N, \xi_N^*, \xi_N^{**}$	0.93	0.93	0.93
Bias towards capital $\alpha_N, \alpha_N^*, \alpha_N^{**}$	0.53	0.43	0.43
Final consumption goods			
Substitution between domestic and imported goods $\phi_A, \phi_A^*, \phi_A^{**}$	1.50	1.50	1.50
Bias towards domestic tradable goods a_H, a_F^*, a_G^{**}	0.68	0.59	0.90
Substitution between tradables and non tradables $\rho_A, \rho_A^*, \rho_A^{**}$	0.50	0.50	0.50
Bias towards tradable goods a_T, a_T^*, a_T^{**}	0.68	0.50	0.50
Final investment goods			
Substitution between domestic and imported goods $\phi_E, \phi_E^*, \phi_E^{**}$	1.50	1.50	1.50
Bias towards domestic tradable goods $\upsilon_H, \upsilon_F^*, \upsilon_G^{**}$	0.50	0.49	0.90
Substitution between tradables and non tradables $\rho_E, \rho_E^*, \rho_E^{**}$	0.50	0.50	0.50
Bias towards tradable goods $\upsilon_T, \upsilon_T^*, \upsilon_T^{**}$	0.78	0.70	0.70

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

Table 2: Gross Mark-ups

	Mark-ups and Elasticities of Substitution		
	Tradables	Nontradables	Wages
H	1.08 ($\theta_T = 13.32$)	1.29 ($\theta_N = 4.44$)	1.60 ($\psi = 2.65$)
REA	1.11 ($\theta_T^* = 10.15$)	1.24 ($\theta_N^* = 5.19$)	1.33 ($\psi^* = 4$)
RW	1.11 ($\theta_T^{**} = 10.15$)	1.24 ($\theta_N^{**} = 5.19$)	1.33 ($\psi^{**} = 4$)

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

Table 3: Real and Nominal Adjustment Costs

Parameter	H	REA	RW
Real Adjustment Costs			
Investment ϕ_I, ϕ_I^*,ϕ_I^{**}	6.00	6.00	6.00
Households' bond positions ϕ_B, ϕ_B^*, ϕ_B^{**}	0.00001	0.00001	0.00001
Nominal Adjustment Costs			
Wages κ_W, κ_W^*, κ_W^{**}	200	200	200
Home produced tradables κ_H, k_H^* k_H^{**}	300	300	50
REA produced tradables κ_H, k_H^* k_H^{**}	300	300	50
RW produced tradables κ_H, k_H^* k_H^{**}	50	50	300
Nontradables κ_N, κ_N^*, κ_N^{**}	500	500	500

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

Table 4: Fiscal and Monetary Policy Rules

Parameter	H	REA	EA	RW
Fiscal policy rule				
$\phi_1, \phi_1^*, \phi_1^{**}$	0.05	1.01	-	1.01
$\phi_2, \phi_2^*, \phi_2^{**}$	1.01	1.01	-	1.01
Common monetary policy rule	-	-		
Lagged interest rate ρ_R, ρ_R^{**}	-	-	0.87	0.87
Inflation ρ_Π, ρ_Π^{**}	-	-	1.70	1.70
GDP growth $\rho_{GDP}, \rho_{GDP}^{**}$	-	-	0.10	0.10

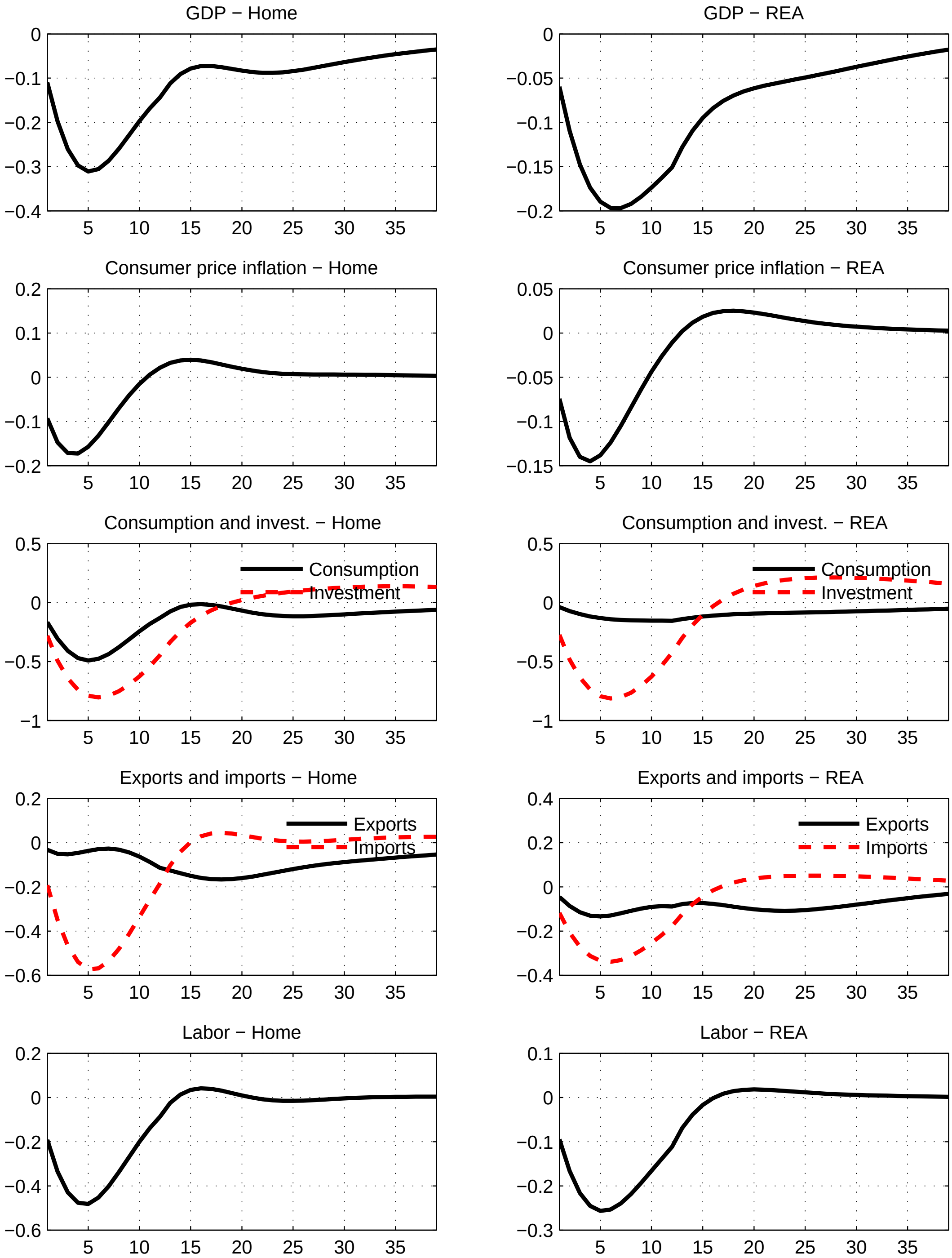
Note: H=Home; REA=rest of the euro area; EA=euro area; RW= rest of the world.
"*" refers to REA, "**" to RW.

Table 5: Main macroeconomic variables (ratio to GDP)

	H	REA	RW
Macroeconomic variables			
Private consumption	61.0	57.1	64.0
Public consumption	20.0	20.0	20.0
Private investment	18.0	16.0	20.0
Imports	29.0	24.3	4.25
Net Foreign Asset Position	0.0	0.0	0.0
GDP (share of world GDP)	0.05	0.17	0.78
Private debt (ratio to annual GDP)	85.0	55.0	–
Short-term public debt (ratio to annual GDP)	13.0	8.0	–
Long-term public debt (ratio to annual GDP)	115.0	90.0	–

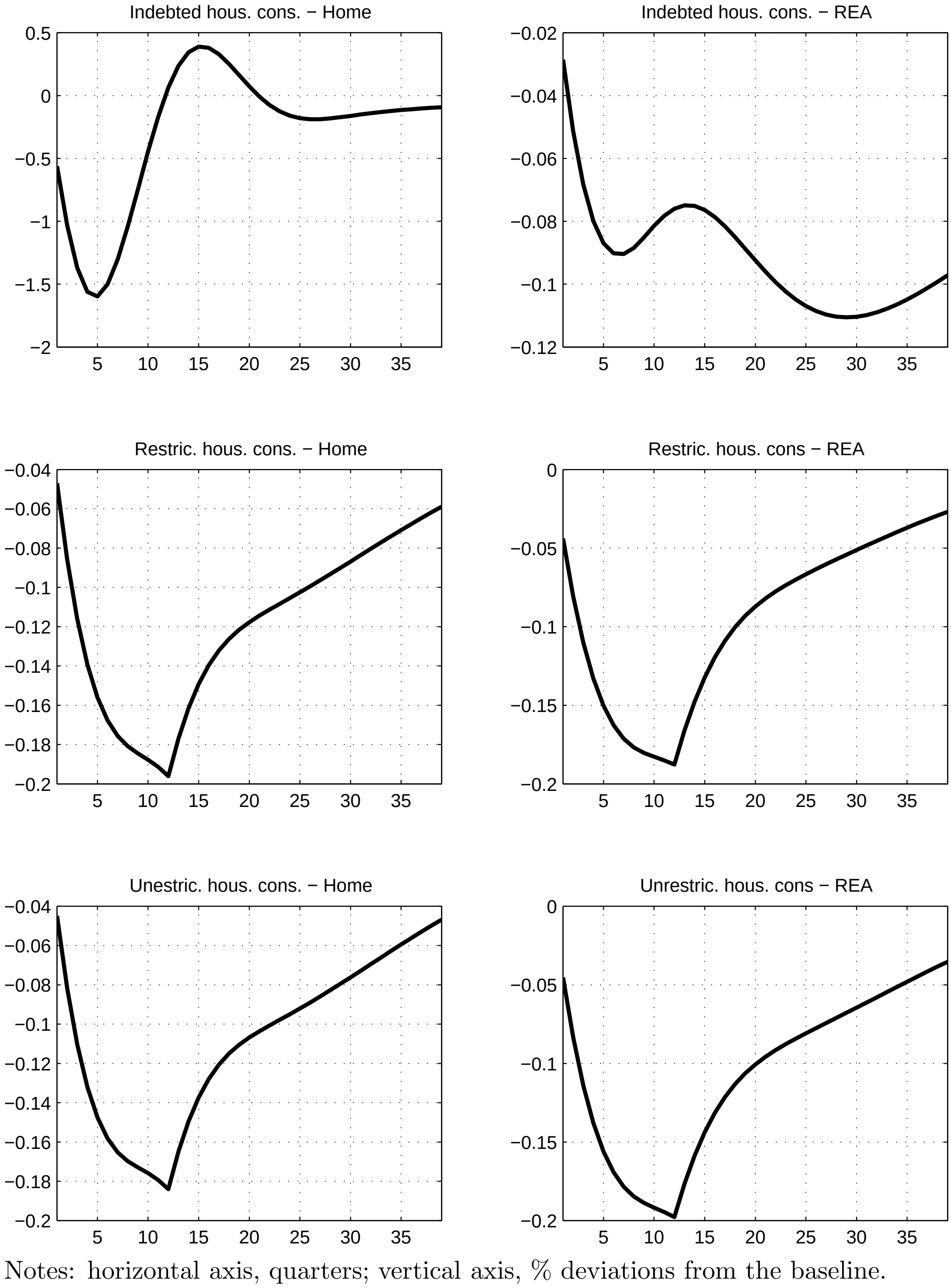
Note: H=Home; REA=rest of the euro area; RW= rest of the world.
"*" refers to REA, "**" to RW.

Figure 1: Negative EA demand shock. Macroeconomic effects.



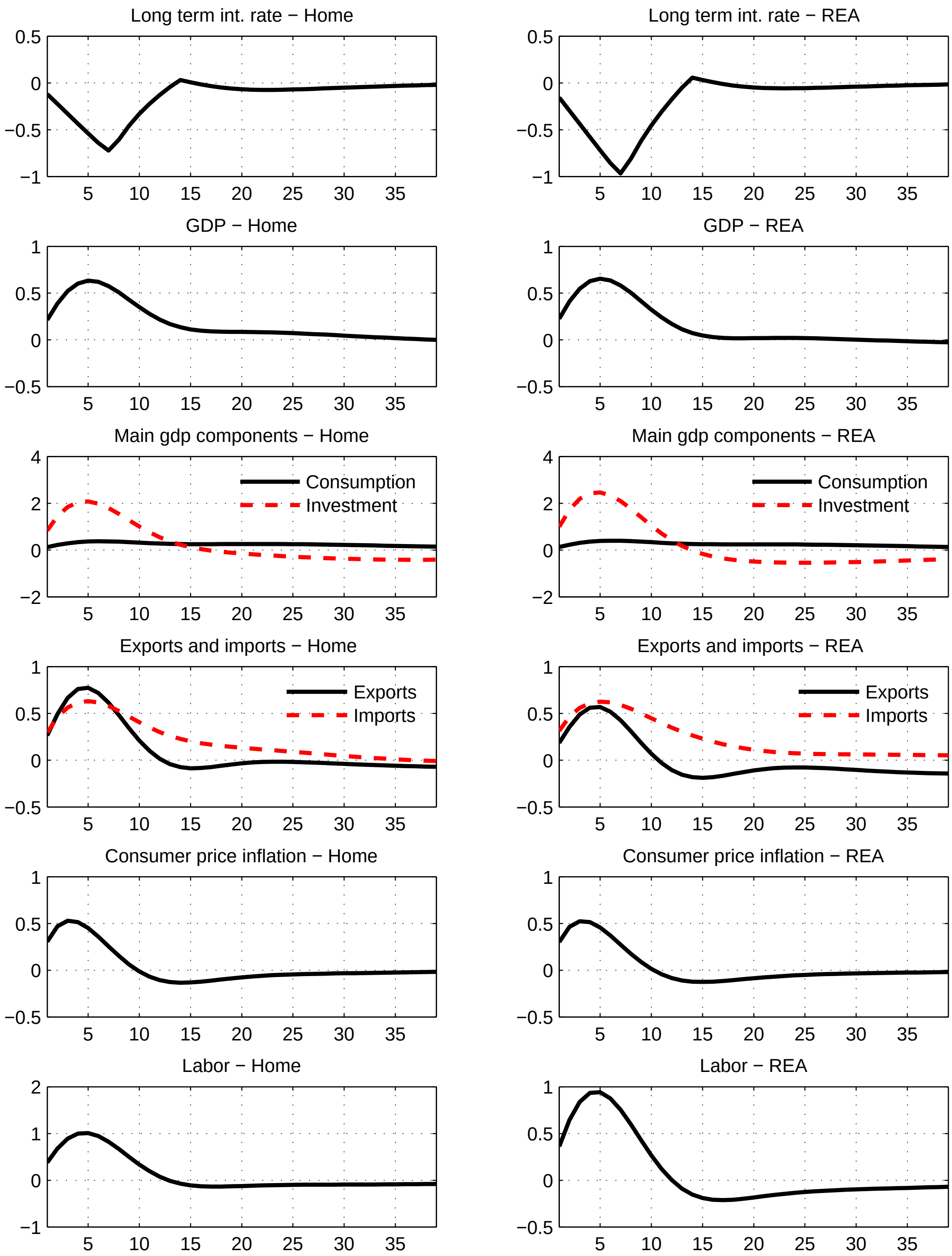
Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline. For inflation, annualized percentage point deviations from the baseline.

Figure 2: Negative EA demand shock. Consumption and asset positions.



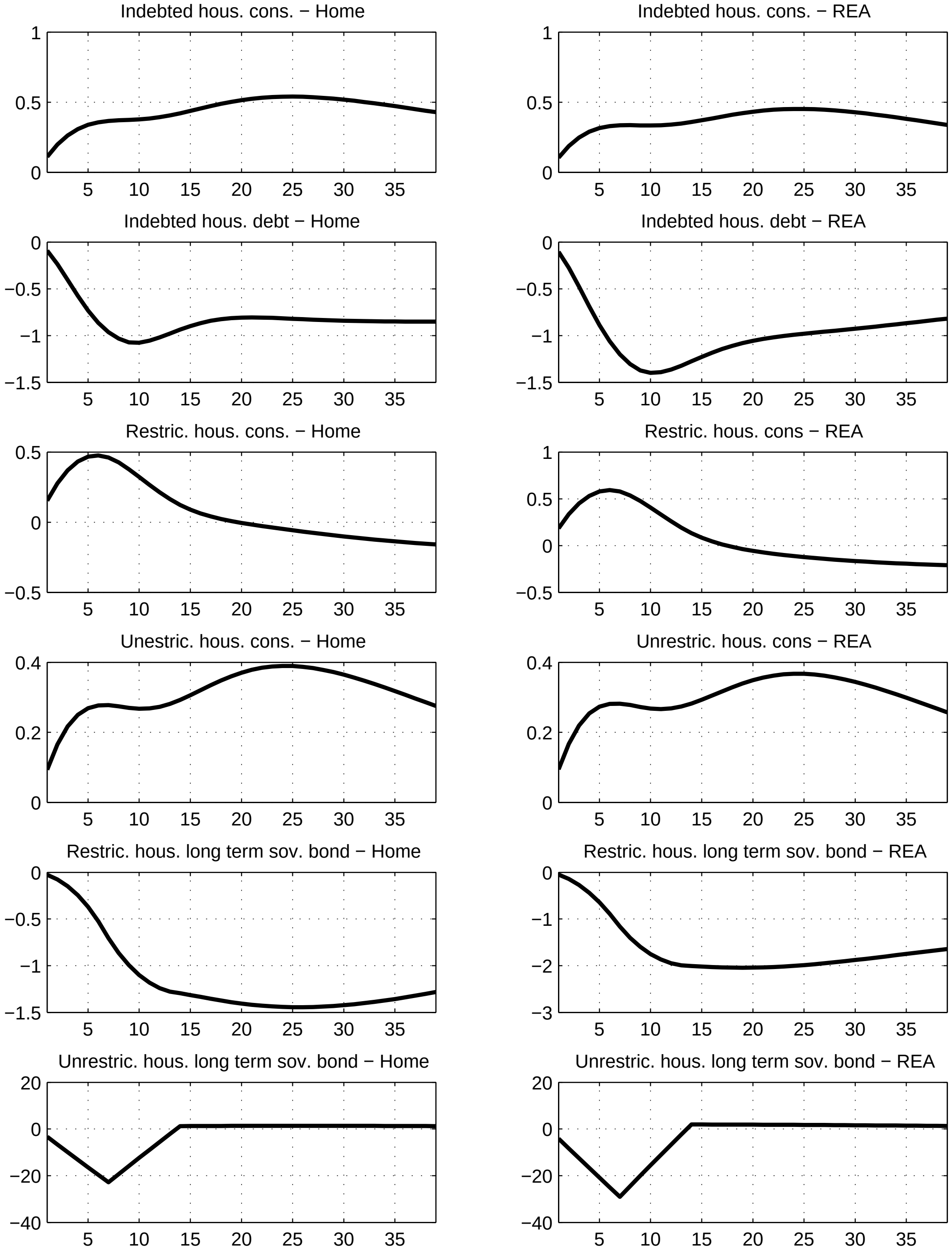
Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline.

Figure 3: Non-standard monetary policy. Macroeconomic effects.



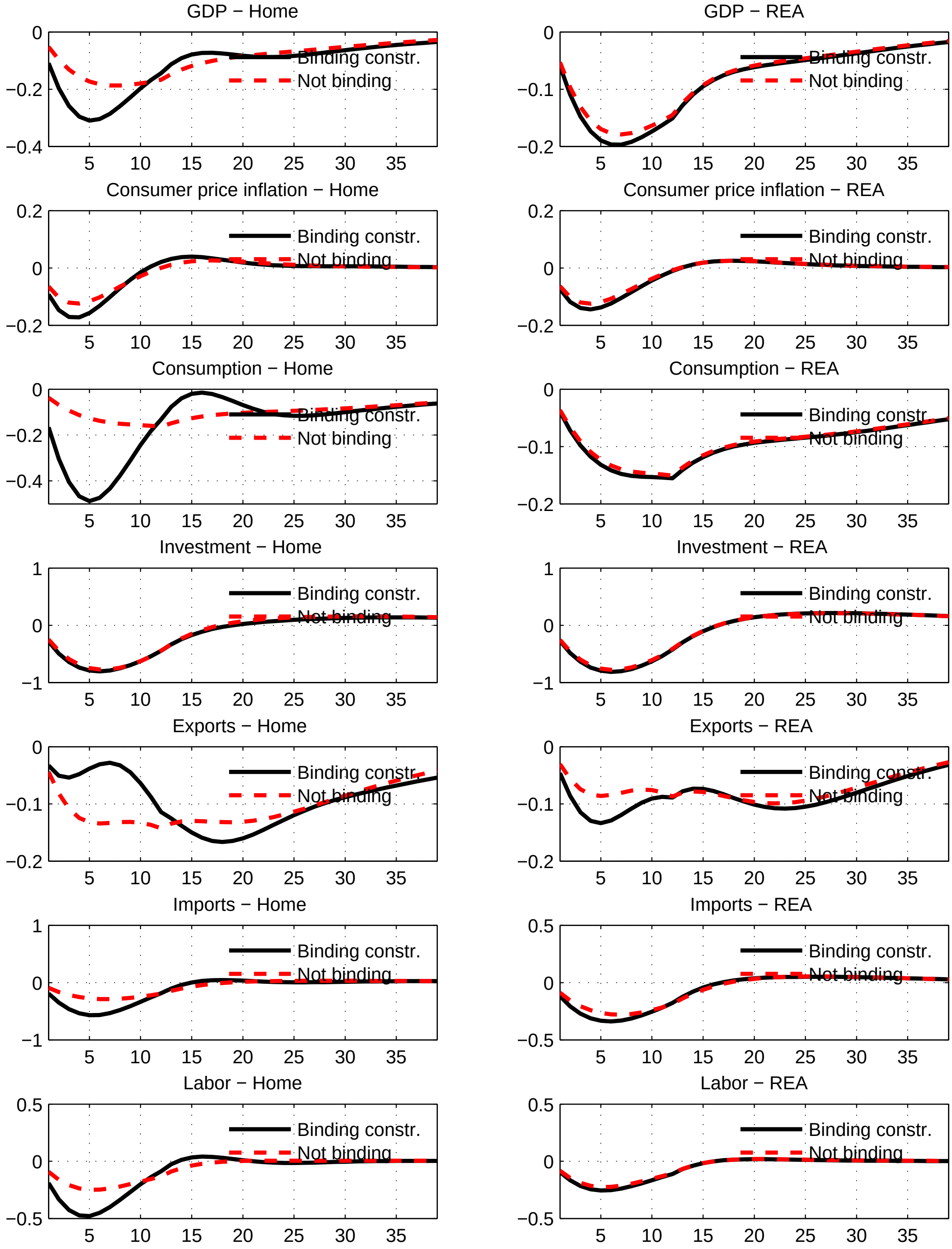
Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline. For interest rates and inflation, annualized percentage point deviations from the baseline.

Figure 4: Non-standard monetary policy. Consumption and asset positions.



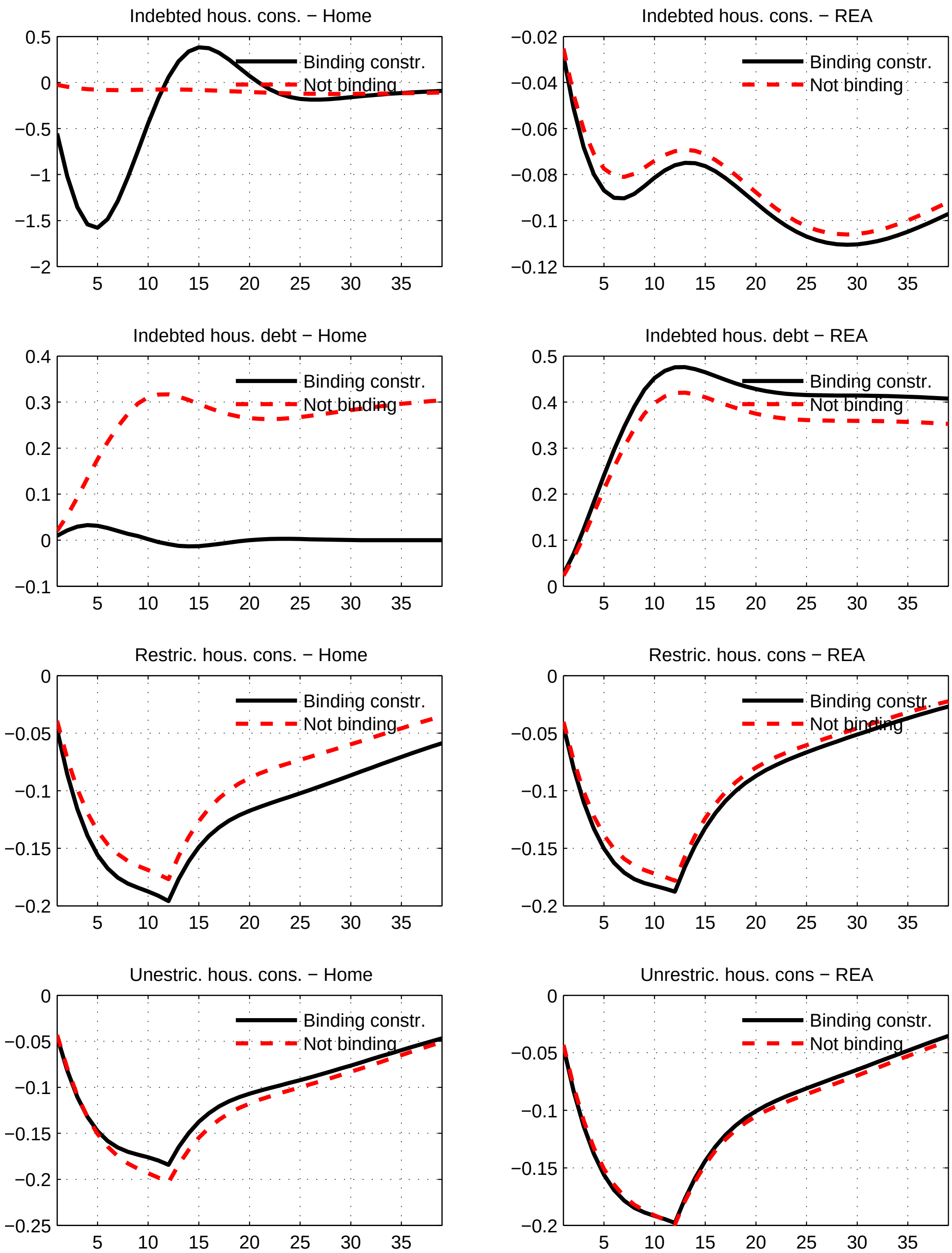
Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline.

Figure 5: Negative EA demand shock and non-binding borrowing constraint. Macroeconomic effects.



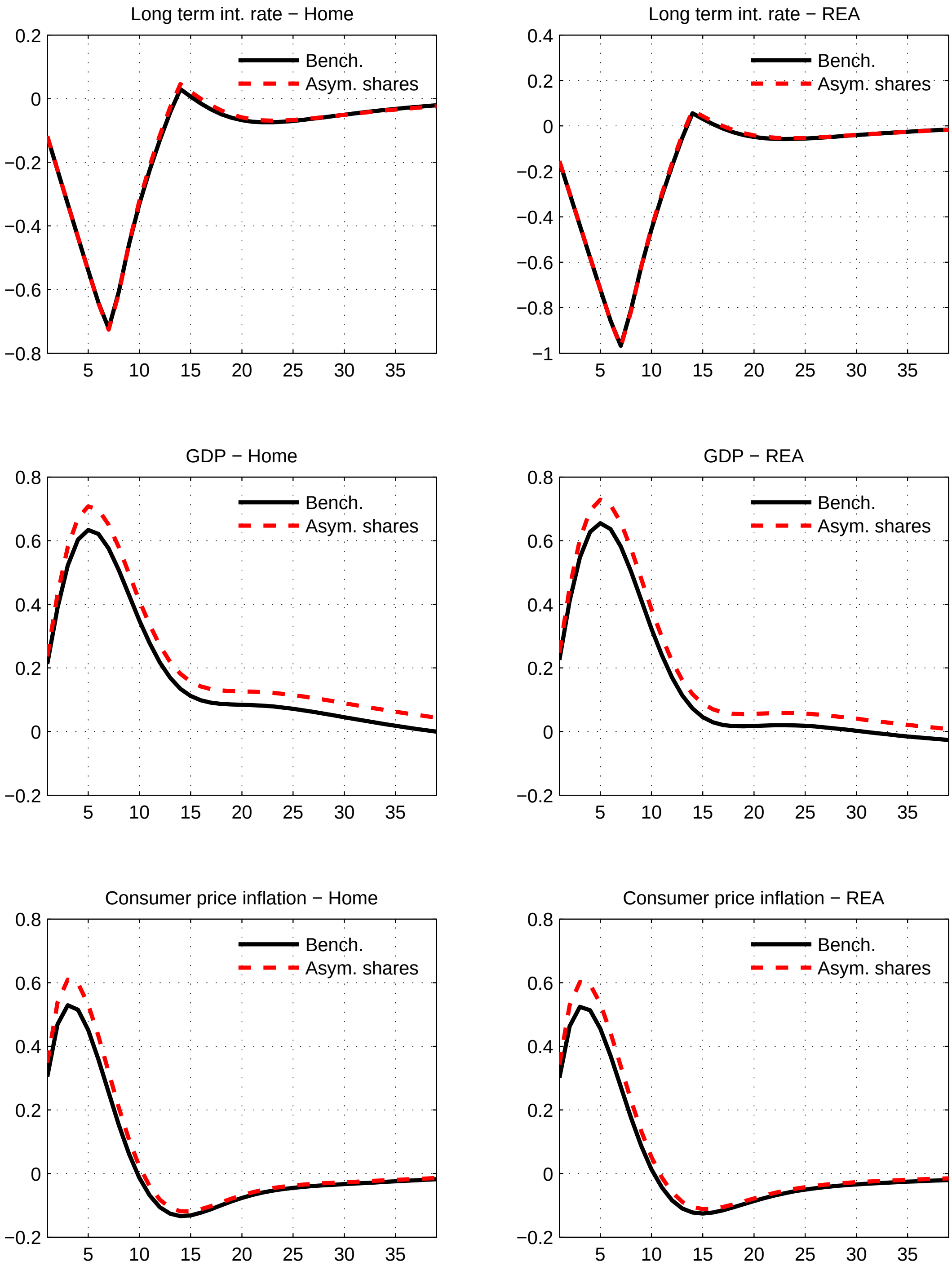
Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline. For inflation, annualized percentage point deviations from the baseline.

Figure 6: Negative EA demand shock and non-binding borrowing constraint. Consumption and asset positions.



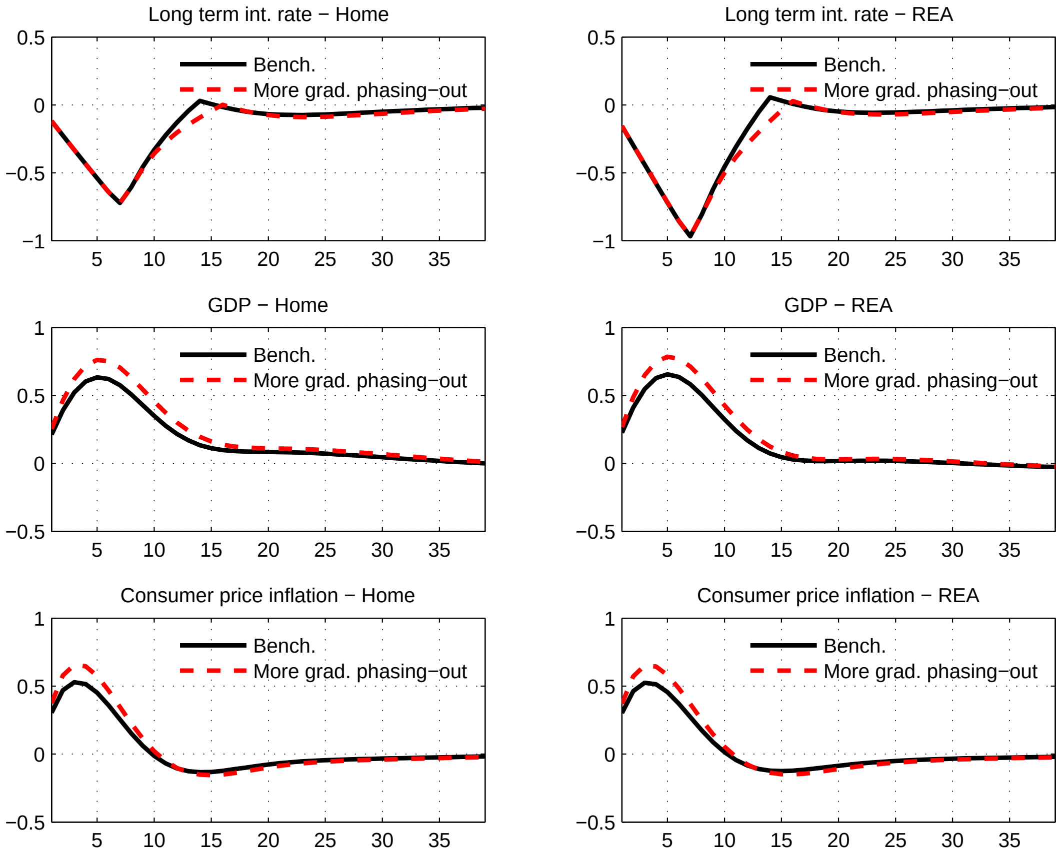
Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline.

Figure 7: Sensitivity on asymmetric sovereign bond holdings.



Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline. For interest rates and inflation, annualized percentage point deviations from the baseline.

Figure 8: Sensitivity on increase in gradualness of EAPP phasing-out.



Notes: horizontal axis, quarters; vertical axis, % deviations from the baseline. For interest rates and inflation, annualized percentage point deviations from the baseline.

Appendix

In this Appendix we report a detailed description of the model except for fiscal and monetary policies and households' optimization problems, which are reported in the main text.[27]

There are three blocs, Home, REA, and RW. In what follows we illustrate the Home economy. The structure of each of the other two regions (REA and the RW) is similar and to save on space we do not report it.

Final consumption and investment goods

There is a continuum of symmetric Home firms producing final nontradable consumption under perfect competition. Each firm producing the consumption good is indexed by $x \in (0, n]$, where the parameter $0 < n < 1$ measures the size of Home. Firms in the REA and in the RW are indexed by $x^* \in (n, n + n^*]$ and $x^{**} \in (n + n^*, 1]$, respectively (the size of the world economy is normalized to 1). The CES production technology used by the generic firm x is

$$A_t(x) \equiv \left(a_T^{\frac{1}{\phi_A}} \left(\begin{array}{l} a_H^{\frac{1}{\rho_A}} Q_{HA,t}(x)^{\frac{\rho_A - 1}{\rho_A}} \\ + a_G^{\frac{1}{\rho_A}} Q_{GA,t}(x)^{\frac{\rho_A - 1}{\rho_A}} \\ + (1 - a_H - a_G)^{\frac{1}{\rho_A}} Q_{FA,t}(x)^{\frac{\rho_A - 1}{\rho_A}} \end{array} \right)^{\frac{\rho_A}{\rho_A - 1} \frac{\phi_A - 1}{\phi_A}} + (1 - a_T)^{\frac{1}{\phi_A}} Q_{NA,t}(x)^{\frac{\phi_A - 1}{\phi_A}} \right)^{\frac{\phi_A}{\phi_A - 1}}$$

where Q_{HA}, Q_{GA}, Q_{FA}, and Q_{NA} are bundles of respectively intermediate tradables produced in Home, intermediate tradables produced in the REA, intermediate tradables produced in the RW, and intermediate nontradables produced in the Home country. The parameter $\rho_A > 0$ is the elasticity of substitution between tradables and $\phi_A > 0$ is the elasticity of substitution between tradable and nontradable goods. The parameter a_H $(0 < a_H < 1)$ is the weight of the Home tradable, the parameter a_G $(0 < a_G < 1)$ the weight of tradables imported from the REA, and the parameter a_T $(0 < a_T < 1)$ the weight of tradable goods.

[27]For a detailed description of the main features of the model see also Pesenti (2008).

The production of investment good is similar. There are symmetric Home firms under perfect competition indexed by $y \in (0, n]$. Firms in the REA and in the RW are indexed by $y^* \in (n, n+n^*]$ and $y^{**} \in (n+n^*, 1]$. Output of the generic Home firm y is

$$E_t(y) \equiv \left(\begin{array}{l} v_T^{\frac{1}{\phi_E}} \left(\begin{array}{l} v_H^{\frac{1}{\rho_E}} Q_{HE,t}(y)^{\frac{\rho_E - 1}{\rho_E}} \\ + v_G^{\frac{1}{\rho_E}} Q_{GE,t}(y)^{\frac{\rho_E - 1}{\rho_E}} \\ + (1 - v_H - v_G)^{\frac{1}{\rho_E}} Q_{FE,t}(y)^{\frac{\rho_E - 1}{\rho_E}} \end{array} \right)^{\frac{\rho_E}{\rho_E - 1} \frac{\phi_E - 1}{\phi_E}} \\ + (1 - v_T)^{\frac{1}{\phi_E}} Q_{NE,t}(y)^{\frac{\phi_E - 1}{\phi_E}} \end{array} \right)^{\frac{\phi_E}{\phi_E - 1}}$$

Finally, we assume that public expenditure C^g is composed by intermediate non-tradable goods only.

Intermediate goods

Demand

Bundles used to produce the final consumption goods are CES indexes of differentiated intermediate goods, each produced by a single firm under conditions of monopolistic competition:

$$Q_{HA}(x) \equiv \left[\left(\frac{1}{s} \right)^{\theta_T} \int_0^n Q(h, x)^{\frac{\theta_T - 1}{\theta_T}} dh \right]^{\frac{\theta_T}{\theta_T - 1}}, \quad (21)$$

$$Q_{GA}(x) \equiv \left[\left(\frac{1}{S - s} \right)^{\theta_T} \int_n^{n+n^*} Q(g, x)^{\frac{\theta_T - 1}{\theta_T}} dg \right]^{\frac{\theta_T}{\theta_T - 1}}, \quad (22)$$

$$Q_{FA}(x) \equiv \left[\left(\frac{1}{1 - S} \right)^{\theta_T} \int_{n+n^*}^1 Q(f, x)^{\frac{\theta_T - 1}{\theta_T}} df \right]^{\frac{\theta_T}{\theta_T - 1}}, \quad (23)$$

$$Q_{NA}(x) \equiv \left[\left(\frac{1}{s} \right)^{\theta_N} \int_0^n Q(i, x)^{\frac{\theta_N - 1}{\theta_N}} di \right]^{\frac{\theta_N}{\theta_T - 1}}, \quad (24)$$

where firms in the Home intermediate tradable and nontradable sectors are respectively indexed by $h \in (0, n]$ and $n \in (0, n]$, firms in the REA by $g \in (n, n + n^*]$, and firms in the RW by $f \in (n + n^*, 1]$. Parameters θ_T, $\theta_N > 1$ are respectively the elasticity of substitution across brands in the tradable and nontradable sector. The prices of the intermediate nontradable goods are denoted $p(i)$. Each firm x takes these prices as given when minimizing production costs of the final good. The resulting demand for intermediate nontradable input i is

$$Q_{A,t}\left(i, x\right) = \left(\frac{1}{s}\right) \left(\frac{P_t\left(i\right)}{P_{N,t}}\right)^{-\theta_N} Q_{NA,t}\left(x\right), \tag{25}$$

where $P_{N,t}$ is the cost-minimizing price of one basket of local intermediates:

$$P_{N,t} = \left[\int_0^n P_t\left(i\right)^{1-\theta_N} di\right]^{\frac{1}{1-\theta_N}}. \tag{26}$$

We can derive $Q_A\left(h, x\right)$, $Q_A\left(f, x\right)$, $C_A^g\left(h, x\right)$, $C_A^g\left(f, x\right)$, P_H, and P_F in a similar way. Firms y producing the final investment goods have similar demand curves. Aggregating over x and y, it can be shown that total demand for intermediate nontradable good i is

$$\begin{aligned} & \int_0^n Q_{A,t}\left(i, x\right) dx + \int_0^n Q_{E,t}\left(i, y\right) dy + \int_0^n C_t^g\left(i, x\right) dx \\ = & \left(\frac{P_t\left(i\right)}{P_{N,t}}\right)^{-\theta_N} \left(Q_{NA,t} + Q_{NE,t} + C_{N,t}^g\right), \end{aligned}$$

where C_N^g is public sector consumption. Home demands for (intermediate) domestic and imported tradable goods can be derived in a similar way.

Supply

The supply of each Home intermediate nontradable good i is denoted by $N^S(i)$:

$$N_t^S\left(i\right) = \left(\left(1 - \alpha_N\right)^{\frac{1}{\xi_N}} L_{N,t}\left(i\right)^{\frac{\xi_N - 1}{\xi_N}} + \alpha^{\frac{1}{\xi_N}} K_{N,t}\left(i\right)^{\frac{\xi_N - 1}{\xi_N}}\right)^{\frac{\xi_N}{\xi_N - 1}}. \tag{27}$$

Firm i uses labor $L^{p}_{N,t}(i)$ and capital $K_{N,t}(i)$ with constant elasticity of input substitution $\xi_N > 0$ and capital weight $0 < \alpha_N < 1$. Firms producing intermediate goods take the prices of labor inputs and capital as given. Denoting W_t the nominal wage index and R^K_t the nominal rental price of capital, cost minimization implies that

$$L_{N,t}(i) = (1-\alpha_N)\left(\frac{W_t}{MC_{N,t}(i)}\right)^{-\xi_N} N^S_t(i) \tag{28}$$

and

$$K_{N,t}(i) = \alpha\left(\frac{R^K_t}{MC_{N,t}(i)}\right)^{-\xi_N} N^S_t(i)$$

where $MC_{N,t}(n)$ is the nominal marginal cost:

$$MC_{N,t}(i) = \left((1-\alpha)W_t^{1-\xi_N} + \alpha\left(R^K_t\right)^{1-\xi_N}\right)^{\frac{1}{1-\xi_N}}. \tag{29}$$

The productions of each Home tradable good, $T^S(h)$, is similarly characterized.

Price setting in the intermediate sector

Consider now profit maximization in the Home intermediate nontradable sector. Each firm i sets the price $p_t(i)$ by maximizing the present discounted value of profits subject to the demand constraint and the quadratic adjustment costs,

$$AC^{p}_{N,t}(i) \equiv \frac{\kappa^p_N}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 Q_{N,t},$$

which is paid in unit of sectorial product $Q_{N,t}$ and where $\kappa^p_N \geq 0$ measures the degree of price stickiness. The resulting first-order condition, expressed in terms of domestic consumption, is

$$p_t(i) = \frac{\theta_N}{\theta_N - 1} mc_t(i) - \frac{A_t(i)}{\theta_N - 1}, \tag{30}$$

where $mc_t(i)$ is the real marginal cost and $A_t(i)$ contains terms related to the presence of price adjustment costs:

$$\begin{aligned} A_t(i) &\approx \kappa_N^p \frac{P_t(i)}{P_{t-1}(i)} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right) \\ &\quad -\beta \kappa_N^p \frac{P_{t+1}(i)}{P_t(i)} \left(\frac{P_{t+1}(i)}{P_t(i)} - 1 \right) \frac{Q_{N,t+1}}{Q_{N,t}}. \end{aligned}$$

The above equations clarify the link between imperfect competition and nominal rigidities. When the elasticity of substitution θ_N is very large and hence the competition in the sector is high, prices closely follow marginal costs, even though adjustment costs are large. To the contrary, it may be optimal to maintain stable prices and accommodate changes in demand through supply adjustments when the average markup over marginal costs is relatively high. If prices were flexible, optimal pricing would collapse to the standard pricing rule of constant markup over marginal costs (expressed in units of domestic consumption):

$$p_t(i) = \frac{\theta_N}{\theta_N - 1} mc_{N,t}(i). \tag{31}$$

Firms operating in the intermediate tradable sector solve a similar problem. We assume that there is market segmentation. Hence the firm producing the brand h chooses $p_t(h)$ in the Home market, a price $p_t^*(h)$ in the REA, and a price $p_t^{**}(h)$ in the RW to maximize the expected flow of profits (in terms of domestic consumption units),

$$E_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left[\begin{array}{c} p_\tau(h) y_\tau(h) + p_\tau^*(h) y_\tau^*(h) + p_\tau^{**}(h) y_\tau^{**}(h) \\ -mc_{H,\tau}(h) \left(y_\tau(h) + y_\tau^*(h) + y_\tau^{**}(h) \right) \end{array} \right],$$

subject to quadratic price adjustment costs similar to those considered for non-tradables and standard demand constraints. The term E_t denotes the expectation operator conditional on the information set at time t, $\Lambda_{t,\tau}$ is the appropriate discount rate, and $mc_{H,t}(h)$ is the real marginal cost. The first order conditions with respect to $p_t(h)$, $p_t^*(h)$, and $p_t^{**}(h)$ are

$$
\begin{aligned}
p_t(h) &= \frac{\theta_T}{\theta_T - 1} mc_t(h) - \frac{A_t(h)}{\theta_T - 1}, &(32)\\
p_t^*(h) &= \frac{\theta_T}{\theta_T - 1} mc_t(h) - \frac{A_t^*(h)}{\theta_T - 1}, &(33)\\
p_t^{**}(h) &= \frac{\theta_T}{\theta_T - 1} mc_t(h) - \frac{A_t^{**}(h)}{\theta_T - 1}, &(34)
\end{aligned}
$$

where θ_T is the elasticity of substitution of intermediate tradable goods, while $A(h)$ and $A^*(h)$ involve terms related to the presence of price adjustment costs:

$$
\begin{aligned}
A_t(h) &\approx \kappa_H^p \frac{P_t(h)}{P_{t-1}(h)} \left(\frac{P_t(h)}{P_{t-1}(h)} - 1 \right) \\
&\quad - \beta \kappa_H^p \frac{P_{t+1}(h)}{P_t(h)} \left(\frac{P_{t+1}(h)}{P_t(h)} - 1 \right) \frac{Q_{H,t+1}}{Q_{H,t}}, \\
A_t^*(h) &\approx \theta_T - 1 + \kappa_H^p \frac{P_t^*(h)}{P_{t-1}^*(h)} \left(\frac{P_t^*(h)}{P_{t-1}^*(h)} - 1 \right) \\
&\quad - \beta \kappa_H^p \frac{P_{t+1}^*(h)}{P_t^*(h)} \left(\frac{P_{t+1}^*(h)}{P_t^*(h)} - 1 \right) \frac{Q_{H,t+1}^*}{Q_{H,t}^*}, \\
A_t^{**}(h) &\approx \theta_T - 1 + \kappa_H^p \frac{P_t^{**}(h)}{P_{t-1}^{**}(h)} \left(\frac{P_t^{**}(h)}{P_{t-1}^{**}(h)} - 1 \right) \\
&\quad - \beta \kappa_H^p \frac{P_{t+1}^{**}(h)}{P_t^{**}(h)} \left(\frac{P_{t+1}^{**}(h)}{P_t^{**}(h)} - 1 \right) \frac{Q_{H,t+1}^{**}}{Q_{H,t}^{**}},
\end{aligned}
$$

where κ_H^p,${\kappa_H^p}^*$,${\kappa_H^p}^{**} > 0$ respectively measure the degree of nominal rigidity in the Home country, in the REA, and in the RW.

Labor Market

In the case of firms in the intermediate nontradable sector, the labor input $L_N(i)$ is a CES combination of differentiated labor inputs supplied by domestic agents and defined over a continuum of mass equal to the country size ($j \in [0, n]$):

$$
L_{N,t}(i) \equiv \left(\frac{1}{n} \right)^{\frac{1}{\psi}} \left[\int_0^n L_t(i,j)^{\frac{\psi-1}{\psi}} \, dj \right]^{\frac{\psi}{\psi-1}}, \tag{35}
$$

where $L(i,j)$ is the demand of the labor input of type j by the producer of good i and $\psi > 1$ is the elasticity of substitution among labor inputs. Cost minimization implies that

$$L_t(i,j) = \left(\frac{1}{n}\right)\left(\frac{W_t(j)}{W_t}\right)^{-\psi} L_{N,t}(j), \tag{36}$$

where $W(j)$ is the nominal wage of labor input j and the wage index W is

$$W_t = \left[\left(\frac{1}{n}\right)\int_0^n W_t(h)^{1-\psi}\, dj\right]^{\frac{1}{1-\psi}}. \tag{37}$$

Similar equations hold for firms producing intermediate tradable goods. Each household is the monopolistic supplier of a labor input j and sets the nominal wage facing a downward-sloping demand obtained by aggregating demand across Home firms. The wage adjustment is sluggish because of quadratic costs paid in terms of the total wage bill,

$$AC_t^W = \frac{\kappa_W}{2}\left(\frac{W_t}{W_{t-1}} - 1\right)^2 W_t L_t, \tag{38}$$

where the parameter $\kappa_W > 0$ measures the degree of nominal wage rigidity and L_t is the total amount of labor in the Home economy.