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EAGLE-FLI. A MACROECONOMIC MODEL OF BANKING AND FINANCIAL INTERDEPENDENCE IN THE EURO AREA

by Nikola Bokan*, Andrea Gerali**, Sandra Gomes***,
Pascal Jacquinot* and Massimiliano Pisani**

Abstract

We incorporate financial linkages into EAGLE, a New Keynesian multi-country dynamic general equilibrium model of the euro area by including financial frictions and country-specific banking sectors. In this new version, called EAGLE-FLI (Euro Area and Global Economy with Financial Linkages), banks collect deposits from domestic household and cross-county interbank markets and raise capital to finance loans to domestic households and firms. In order to borrow from local (regional) banks, households use domestic real estate whereas firms use both domestic real estate and physical capital as collateral. These features, together with a full description of trade balance and real exchange rate dynamics and a broad array of financial shocks, allow us to assess the domestic and cross-country macroeconomic effects of financial shocks accurately. Our results support the views that (1) business cycles in the euro area can be driven not only by real shocks but also by financial ones, (2) the financial sector could amplify the transmission of (real) shocks and (3) financial/banking shocks and banking sectors can be sources of business cycle asymmetries and spillovers across countries in a monetary union.

JEL Classification: E51, E32, E44, F45, F47.
Keywords: Banks, DSGE models, econometric models, financial frictions, open-economy macroeconomics, policy analysis.

Contents

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* European Central Bank.
** Bank of Italy.
*** Bank of Portugal.

1 Introduction[1]

The recent financial crisis, which has resulted in a long period of economic stagnation and extremely low inflation, especially in the euro area (EA), and the ensuing debate on policy responses (in particular by central banks) have widely increased the need for understanding how domestic and cross-country financial factors might affect macroeconomic performance in a monetary union such as the EA. Cross-country heterogeneous conditions in financial markets and banking sectors within the union can make it difficult for the common monetary policy to guarantee the union-wide macroeconomic stability, while calling for macroprudential policies to foster financial stability at a country and, hence, union level. Thus, understanding the role of country-specific structural financial and banking features, their interaction within and across regions and their effect on the transmission mechanism of monetary policy is crucial for a proper analysis of monetary and financial stabilization issues in a monetary union, and in particular for a thorough assessment of policy responses in the EA in the aftermath of the recent financial crisis.

To tackle these issues we enrich a multi-country model of the EA called EAGLE (Euro Area and GLobal Economy) model with financial frictions, banking sectors and a cross-country interbank market.[2] This paper describes the new model setup, labeled EAGLE-FLI (Euro Area and GLobal Economy with Financial LInkages),[3] and transmission mechanism via a set of simulations, that shows the macroeconomic effects of several financial shocks, to illustrate its usefulness from a policy perspective.

The original EAGLE model is a large-scale microfounded model developed for the analysis of spillovers and macroeconomic interdependence across the different countries belonging to the EA and between them and other countries outside the monetary union. The open economy version of the New Keynesian paradigm, so called New Open Economy Macroeconomics framework, constitutes EAGLE's theoretical kernel and guarantees a nontrivial role for monetary, exchange rate, fiscal and structural policy measures. The microfoundations of the model together with its rich structure allow for a quantitative analysis in a theoretically coherent and fully consistent model setup, clearly spelling out the policy implications.[4]

EAGLE-FLI adds the following features to the original EAGLE framework. First, we introduce two types of households, namely "borrowers"and "savers". Second, we include a banking

[1]We thank Günter Coenen for invaluable support. We thank two anonymous referees, participants at the Working Group on Econometric Modeling, the EAGLE Network meetings, the 2015 DYNARE Conference. The opinions expressed are those of the authors and do not reflect views of their respective institutions. Any remaining errors are the sole responsibility of the authors.

[2]See Gomes, Jacquinot and Pisani (2010, 2012) for the description of the standard EAGLE model.

[3]Jointly developed by staff of Bank of Portugal, Bank of Italy, Croatian National Bank and European Central Bank, EAGLE-FLI is a project of the EAGLE Network, under the auspices of the Working Group on Econometric Modeling of the European System of Central Banks.

[4]The EAGLE setup builds on the New Area Wide Model (NAWM, Coenen, McAdam and Straub, 2008). See also the IMF's Global Economy Model (GEM, Laxton and Pesenti, 2003 and Pesenti, 2008), the Bank of Canada's version of GEM (Lalonde and Muir, 2007), the Federal Reserve Board's SIGMA (Erceg, Guerrieri and Gust, 2006), the European Commission's QUEST (Ratto, Roeger and in't Veld, 2009), and IMF's Global Integrated Monetary Fiscal Model (GIMF, Kumhof and Laxton, 2007).

sector that intermediates credit flows (banking loans and deposits) in each of the four regions of the model. Third, we introduce a real estate sector in the economy that provides housing services to households, a stock of collateral to borrowers and that is used as an input in production. In each region, a bank collects deposits from domestic savers, raises capital subject to a regulatory requirement and lends both to domestic borrowing households and entrepreneurs, subject to a collateral constraint written on their real estate holdings and, for entrepreneurs, also on their physical capital. In addition, only banks located in the two EA regions have access to an interbank market to exchange funds cross-country. Fourth, we enrich the model with a set of financial shocks, such as shocks to the loan-to-value (LTV) ratio, the amount of resources that banks desire to lend in the interbank market, and the bank capital requirement. The shocks are simulated under perfect foresight, so households and firms perfectly anticipate their intertemporal path, but not the value in the initial period (the "surprise"). We also report a sensitivity analysis to further show the relevance of some key financial parameters for the transmission of the shocks.

Our results aim at explaining the domestic and cross-country transmission mechanism of various shocks in a monetary union model where financial factors do matter. Even though the analysis does not aim to quantitatively explain neither the EA business cycle nor the recent financial crisis, the results support the views that (1) the business cycles in the EA can be driven not only by real shocks, but also by financial shocks, (2) the financial sector could amplify the transmission of (real) shocks, and (3) the financial/banking shocks and the banking sectors can be a source of business cycle asymmetries across countries in a monetary union.

The EAGLE-FLI setup builds on several earlier contributions.[5] The distinction between borrowers, entrepreneurs and savers follows Iacoviello (2005). As in that contribution, we assume that entrepreneurs and a fraction of households (the "borrowers") are more impatient than remaining households (the "savers"), i.e. the former have a lower discount rate than the latter. Thus, the corresponding borrowing constraints are binding in the steady state and in its neighborhood. The banking sector is akin to the one in Iacoviello (2015).[6]

Regarding the capital requirement ratio, we follow Kollmann (2013) and Kollmann, Ratto and Roeger (2013), and impose that in every period the bank capital should not be less than a (possibly time-varying) fraction of the bank loans to domestic households and entrepreneurs in the same period.

Kollmann (2013) and Kollmann, Ratto and Roeger (2013) consider the case of a global bank lending domestically and abroad. Different from them, we do not have a "global" bank that originates cross-border loans. Instead, we have country-specific banks that lend to and receive deposits from domestic agents and that, in the case of EA blocs, lend to each other in the EA

[5]In line with these contributions, we assume a cashless economy, so there is no explicit role for money. The monetary policy rate, set according to a Taylor rule, is linked to the other interest rates, including the one holding in the interbank market, via no-arbitrage conditions obtained from banks', households' and entrepreneurs' maximization problems.

[6]We follow Iacoviello (2015) and assume that entrepreneurs borrow against real estate and physical capital. This is different from Iacoviello (2005), where both borrowers and entrepreneurs use real estate as collateral.

interbank market. Allowing banks to lend and borrow at international level is different from allowing households to do the same, as they maximize different objectives subject to different constraints, such as the capital requirement. EAGLE-FLI features financial spillovers that directly affect banks behavior, and only indirectly (via banks) the foreign borrowers while in Kollmann (2013) and Kollmann, Ratto and Roeger (2013) there is a direct spillover from bank to foreign borrowers.

The "region-specific" banking sector setup is also used in Brzoza-Brzezina, Kolasa, and Makarski (2015), who develop a monetary union model of the EA featuring two regional banking sectors. Guerrieri, Iacoviello, and Minetti (2012) consider a two-region model calibrated to the EA featuring regional banks and sovereign debt default. Different from these contributions, we introduce a "region specific"banking sector in a large-scale open-economy New Keynesian dynamic general equilibrium model. Thus, the model includes several ingredients needed for the quantitative assessment of cross-country financial and banking spillovers in a monetary union.[7]

The paper is organized as follows. Section 2 shows the setup of the banking and financial sectors. Section 3 reports the calibration. Section 4 contains the results of simulating financial shocks and the sensitivity analysis. Section 5 concludes.

2 The model

In this section we report the novel features that characterize the EAGLE-FLI setup. The model features the world economy, whose size is normalized to one. It consists of four blocs (each bloc represents a country or a region). $s^H, s^{REA}, s^{US} > 0$ are respectively the sizes of Home, REA and US blocs, and $s^H + s^{REA} + s^{US} < 1$. For each bloc, the size of the economy corresponds to the size of population (sum of households, bankers, entrepreneurs) and to the size of each firms' sector (intermediate tradable, intermediate nontradable, final nontradable sectors). We assume that two blocs, labelled Home (H) and rest of the EA (REA), are members of a monetary union, the EA. Thus, they share the monetary policy authority and the nominal exchange rates against the remaining two blocs, assumed to represent the U.S. (US) and the rest of the world (RW).

In what follows we focus on a description of the H bloc of the EA. We describe the banking sector, households' and entrepreneurs' behavior, the monetary authority, market clearing conditions, net foreign asset position and international relative prices. Other blocs are similar, so we do not report the related equations to save on space. The exception is that the US and RW blocs differ from those of the EA because their banking sectors do not lend/borrow in a cross-border interbank market.

[7]Gerali et al. (2010) estimate a model of the EA as a whole featuring a banking sector. Lombardo and McAdam (2012) estimate a model of the EA as a whole with financial frictions.

2.1 The banking sector

The Home economy is populated by a continuum of banks that act under perfect competition and, hence, maximize profits taking interest rates as given and choosing the optimal amount of assets and liabilities. The banks are a fraction $0 < \omega_B < 1$ of the H bloc population. They have the same preferences, constraints and initial asset positions. Thus, they make the same optimal choices and it is possible to assume a representative bank (the "bank"). The banking sector intermediates funds between agents that cannot directly lend to and borrow from each other (a crucial assumption for including the banking sector in a meaningful way in the model). The bank finances loans to domestic impatient households (the "borrowers") and to domestic entrepreneurs by collecting deposits of domestic patient households (the "savers") and raising capital. Moreover, the Home bank takes a position in the (cross-country) EA interbank market.

Utility. The lifetime utility function of the representative bank is defined in terms of real dividends

$$E_t \sum_{k=0}^{\infty} (\beta_B)^k \frac{1}{1-\sigma} \left(\frac{DIV_{t+k}^B}{P_{t+k}^C} \right)^{1-\sigma}, \tag{1}$$

where E_t is the expectation operator, $0 < \beta_B < 1$ is the discount factor, $1/\sigma > 0$ is the intertemporal elasticity of substitution, DIV_t^B represents nominal dividends from banking intermediation activity and P_t^C is the domestic private consumption deflator.

The budget constraint. Deposits, loans, and the position in the interbank market are all defined as one-period euro-denominated nominal assets or liabilities. The bank's nominal budget constraint in period t is:

$$\begin{aligned} DIV_t^B \quad = \quad & -L_t + R_{t-1}^L L_{t-1} - L_t^{IB} + R_{t-1}^{IB} L_{t-1}^{IB} \\ & + D_t^{Supply} - R_{t-1}^D D_{t-1}^{Supply} \\ & - P_t^C \Gamma_{L,t} - P_t^C \Gamma_{IB,t} - P_t^C \Gamma_{X,t}, \end{aligned} \tag{2}$$

where L_t denotes the amount of loans granted to domestic entrepreneurs and "borrowers" at the predetermined gross interest rate R_t^L (it is paid at the beginning of period $t+1$ and it is known in period t);[8] L_t^{IB} is the amount of loans granted to the REA banking sector in EA interbank market at the gross interest rate R_t^{IB}; D_t^{Supply} denotes households deposits, that pay the gross interest rate R_t^D. The terms $\Gamma_{L,t}$, $\Gamma_{IB,t}$ and $\Gamma_{X,t}$ are costs the bank faces when adjusting the amount of loans granted, the position in the interbank market and the excess bank capital, respectively. They are specified in "real" terms, i.e. in consumption units (so they are multiplied by the consumption deflator P_t^C). The "real" cost $\Gamma_{L,t}$ (in terms of consumption units) is defined

[8] The same assumption holds for other interest rates.

in terms of changes in loans to allow for a gradual response to a given shock:

$$\Gamma_{L,t} \equiv \frac{\gamma_L}{2}\left(\frac{l_t}{l_{t-1}} - 1\right)^2,$$

where $\gamma_L > 0$ is a parameter, $l_t = \frac{L_t}{P_t^C}$ (i.e. the amount of loans measured in consumption units). The remaining costs will be defined below.

The interbank market. The H bank can borrow from or lend to the REA bank in the EA interbank market, subject to the following "real" adjustment cost

$$\Gamma_{IB,t} \equiv \frac{\gamma_{IB}}{2}\left(l_t^{IB} - \frac{\kappa^{IB}\overline{p}^Y\overline{Y}}{\omega_B}\right)^2, \tag{3}$$

where $\gamma_{IB} > 0$ is a parameter and $l_t^{IB} \equiv \frac{L_t^{IB}}{P_t^C}$. The adjustment cost introduces a wedge between the interest rate on interbank loans and the interest rate on deposits. $\overline{p}^Y$ and $\overline{Y}$ represent the steady-state output deflator (expressed in real terms, i.e. divided by the consumption deflator) and real output, respectively. The parameter

$$\kappa_{IB} \equiv \frac{\omega_B \overline{l}^{IB}}{\overline{p}^Y\overline{Y}} \tag{4}$$

is the steady-state interbank aggregate loan-to-GDP ratio (where $\overline{l}^{IB}$ is the steady-state amount of interbank loans by the representative H bank, measured in consumption units).

The interbank market is formalized in a rather stylized way. The model represents a cashless economy (see Woodford, 1998) so we abstract from money and, hence, from interbank liquidity as well. However, the introduction of this market in the model allows us to evaluate cross-country spillovers directly associated with one regional bank's behavior towards the other regional bank. This is relevant in the light of the recent EA economic history, characterized by relevant changes in the amount of cross-country interbank lending. In particular, introducing the interbank market allows to get a bank-specific shock by exogenously shocking its position on this market via the parameter κ_{IB}. This can be interpreted as a change in the long-run "desired"amount of interbank lending, that may be related to factors not formalized such as changes in liquidity needs or attitude toward risk.

Capital requirement. As in Kollmann (2013), the bank faces a regulatory capital requirement, i.e., its period t nominal capital

$$K_t^B = L_t - D_t^{Supply} + L_t^{IB} \tag{5}$$

should not be less than a (possibly time-varying) fraction $0 < \Upsilon_{K,t} < 1$ of its loans to domestic households and entrepreneurs in the same period, L_t.[9] We define the nominal excess bank capital, at the end of period t, as

$$X_t \equiv (1-\Upsilon_{K,t})L_t - D_t^{Supply} + L_t^{IB}. \tag{6}$$

We assume it is costly, in terms of consumption units, for the bank to deviate from the long-run (steady-state) value of excess bank capital, according to the following quadratic function:[10]

$$\Gamma_{X,t} \equiv \frac{\gamma_X}{2}\left(x_t - \overline{x}\right)^2, \tag{7}$$

where $\gamma_X > 0$ is a parameter, $x_t \equiv \frac{X_t}{P_t^C}$ is excess bank capital expressed in consumption units and $\overline{x}$ is its steady-state value. This adjustment cost introduces a wedge between the interest rate on domestic loans and the interest rate on deposits.

First order conditions (FOC). The representative bank maximizes lifetime utility (1) subject to its budget constraint (2) and the cost from deviating from the capital requirement (7) (given excess bank capital definition 6) with respect to dividends, deposit supply, loans supply and interbank position. Variables are expressed in "real" terms by dividing them by the consumption price deflator P_t^C (thus $div_t^B \equiv DIV_t^B/P_t^C$).

The implied FOC are:

- marginal utility of dividends $\Lambda_{B,t}$

$$\Lambda_{B,t} = \left(div_t^B\right)^{-\sigma}; \tag{8}$$

- deposit supply

$$\Lambda_{B,t} = \beta_B E_t\left[\Lambda_{B,t+1} R_t^D \Pi_{C,t+1}^{-1}\right] - \Lambda_{B,t}\gamma_X\left(x_t - \bar{x}\right), \tag{9}$$

where $\Pi_{C,t+1} \equiv \frac{P_{t+1}^C}{P_t^C}$;

- loans supply

$$\begin{aligned}\Lambda_{B,t} \;=\; & \beta_B E_t\left[\Lambda_{B,t+1} R_t^L \Pi_{C,t+1}^{-1}\right] - \gamma_L \Lambda_{B,t}\left(\frac{l_t}{l_{t-1}} - 1\right)\frac{1}{l_{t-1}} + \beta_B \gamma_L E_t\left[\Lambda_{B,t+1}\left(\frac{l_{t+1}}{l_t} - 1\right)\frac{l_{t+1}}{l_t^2}\right] \\ & -\Lambda_{B,t}\gamma_X(1-\Upsilon_K)\left(x_t - \bar{x}\right);\end{aligned} \tag{10}$$

[9] Bank capital requirements can limit moral hazard in the presence of informational frictions and deposit insurance. We do not model this issue and take the capital requirement as given. Moreover, for simplicity, we assume that interbank loans are not subject to the capital requirement.

[10] In the steady-state equilibrium the capital requirement is satisfied with equality. Thus $X = (1-\Upsilon_K)L - D^{Supply} + L^{IB} = K^B - \Upsilon_K L \geq 0$.

- interbank loans

$$\Lambda_{B,t} = \beta_B E_t \left[\Lambda_{B,t+1} R_t^{IB} \Pi_{C,t+1}^{-1} \right] - \Lambda_{B,t} \gamma_{IB} \left(l_t^{IB} - \frac{\kappa^{IB} \overline{p}^Y \overline{Y}}{\omega_B} \right) - \Lambda_{B,t} \gamma_X \left(x_t - \bar{x} \right). \quad (11)$$

2.2 Households

The Home economy is populated by a continuum of two types of households: patient ("savers") and impatient ("borrowers"). I-type households are patient while J-type are impatient households. The savers are a fraction $(1 - \omega_J - \omega_E - \omega_B)$ of the H population, where ω_J and ω_E ($\omega_J, \omega_E > 0$, $\omega_J + \omega_E + \omega_B < 1$) are the shares of impatient households and entrepreneurs in the H population, respectively. Within each type, agents have the same preferences, constraints and initial asset positions. Each household offers a differentiated labor service to domestic firms and acts as wage setter, under monopolistic competition. Each nominal wage is set according to a Calvo-type mechanism (Calvo, 1983). It is assumed there is perfect wage risk-sharing across households of the same type. Thus, it is possible to assume a representative patient household and a representative impatient household (there is also a representative entrepreneur, as reported in Section 2.3). These two types of households differ in terms of their discount factors, whereby patient households' discount factor is larger than that of impatient households ($\beta_I > \beta_J$). Thus, in equilibrium, impatient households are net borrowers while patient households are net lenders *vis-à-vis* the domestic bank.[11] Both types of households consume and work. Savers have access to multiple financial assets while constrained households can only borrow from the domestic banking sector.

Patient household ("Saver")

Utility. The representative patient household, labelled "saver", gets utility from consumption of the nondurable composite good, $C_{I,t}$ (subject to external habit formation) and from housing services $H_{I,t}$ and gets disutility from working $N_{I,t}$

$$E_t \left[\sum_{k=0}^{\infty} (\beta_I)^k \left(\frac{1-\kappa}{1-\sigma} \left(\frac{C_{I,t+k} - \kappa C_{I,t+k-1}}{1-\kappa} \right)^{1-\sigma} + \iota_I \ln H_{I,t+k} - \frac{1}{1+\zeta} N_{I,t+k}^{1+\zeta} \right) \right], \quad (12)$$

where $0 < \beta_I < 1$ is the discount factor, $0 \leq \kappa \leq 1$ measures the degree of external habit formation in consumption, $\sigma > 0$ denotes the inverse of the intertemporal elasticity of substitution, $\iota_I > 0$ is a parameter for utility from housing services and $\zeta > 0$ is the inverse of the elasticity of work effort with respect to the real wage (Frisch elasticity).

Budget constraint. The patient household provides work to firms in the two intermediate goods production sectors under monopolistic competition and sets wages $W_{I,t}$ in a staggered

[11] For discount factor heterogeneity, see Iacoviello (2005).

way, *à la* Calvo (1983) with indexation.[12] She holds positions in euro-denominated domestic sovereign bonds, in internationally traded US dollar-denominated bonds and euro-denominated bonds (the last assumption holds only for households in the two EA blocs). She also deposits in the domestic bank. The nominal budget constraint is:

$$\begin{aligned} & D_t^{Dem} - R_{t-1}^D D_{t-1}^{Dem} + B_{I,t} - B_{I,t-1} R_{t-1} + B_{I,t}^{EA} - B_{I,t-1}^{EA} R_{t-1} \\ & + S_t^{H,US} B_t^{US} - S_t^{H,US} B_{t-1}^{US} R_{t-1}^{US} \\ = \; & (1 - \tau_{N,t} - \tau_{W_h,t}) W_{I,t} N_{I,t} + (1 - \tau_{D,t}) DIV_t^F - Q_t^H (H_{I,t} - (1 - \delta_H) H_{I,t-1}) \\ & - (1 + \tau_{C,t}) P_t^C C_{I,t} - P_t^C \Gamma_{DH,t} + TR_t - T_t, \end{aligned} \tag{13}$$

where D_t^{Dem} is demand for bank deposits; $B_{I,t}$ is the position in the domestic government bonds, traded only domestically between patient household and the government and paying the EA (gross) monetary policy rate R_t; $B_{I,t}^{EA}$ is the position in the euro-denominated bond, traded between EA patient households and paying the EA monetary policy rate R_t; B_t^{US} is holdings of bonds denominated in US dollars, paying the (gross) interest rate R_t^{US}, set by the US central bank, and converted in euro currency by the Home nominal exchange rate relative to the US, $S_t^{H,US}$ (euro *per* unit of US dollar).[13] For income, $W_{I,t}N_{I,t}$ is labor income ($0 < \tau_{N,t}$, $\tau_{W_h,t} < 1$ represent tax rates on labor and payrolls, respectively, both possibly time-varying); DIV^F is income from ownership of domestic firms (other than banks) and $0 < \tau_{D,t} < 1$ the related tax rate. For expenditures, Q_t^H is the price of housing ($0 < \delta_H < 1$ is the depreciation rate of the housing stock, as housing is formalized as a durable good), $0 < \tau_{C,t} < 1$ is tax rate on (nondurable) consumption good, and Γ_{DH} is the cost of adjusting deposits, which is defined as

$$\Gamma_{DH,t} \equiv \frac{\gamma_{DH}}{2} \left(d_t^{Dem} - \kappa^D \frac{\overline{p}^Y \overline{Y}}{1 - \omega_J - \omega_E - \omega_B} \right)^2, \tag{14}$$

where $d_t^{Dem} \equiv \frac{D_t^{Dem}}{P_t^C}$ and

$$\kappa^D \equiv \frac{(1 - \omega_J - \omega_E - \omega_B) \, \bar{d}^{Dem}}{\overline{p}^Y \overline{Y}} \tag{15}$$

is the steady-state deposit-to-GDP, where $(1 - \omega_J - \omega_E - \omega_B) \, \bar{d}^{Dem}$ are *per capita* aggregate deposits and $\overline{p}^Y \overline{Y}$ is *per capita* aggregate output, both computed in steady state and expressed in consumption units. Finally, the terms TR_t and T_t represent (gross) *lump-sum* transfers and taxes respectively. They are set, together with public spending and tax rates, by the domestic fiscal authority.

FOC. The household maximizes her lifetime utility subject to the budget constraint taking all prices but wages as given. All nominal variables in the budget constraint are expressed in

[12] For details see Gomes, Jacquinot and Pisani (2010, 2012).

[13] As standard in the literature, we add an adjustment cost to the interest rate paid by the US bond so to make the bond position (and, hence, the model) stationary.

"real" terms by dividing them by the consumption price deflator P_t^C. Focusing on the new features of the model, namely housing and bank deposits, we obtain the following FOC:

- marginal utility of consumption $\Lambda_{I,t}$

$$\Lambda_{I,t}(1+\tau_C) = \left(\frac{C_{I,t} - \kappa C_{I,t-1}}{1-\kappa}\right)^{-\sigma}; \tag{16}$$

- deposits demand

$$\Lambda_{I,t} = \beta_I E_t \left[\Lambda_{I,t+1} R_t^D \Pi_{C,t+1}^{-1}\right] - \Lambda_{I,t}\gamma_{DH}\left(d_t^{Dem} - \frac{\kappa^D \overline{p}^Y \overline{Y}}{1-\omega_J-\omega_E-\omega_B}\right); \tag{17}$$

- real estate demand (where $q_t^H \equiv Q_t^H / P_t^C$)

$$\Lambda_{I,t} q_t^H = \frac{\iota_I}{H_{I,t}} + \beta_I E_t \left[\Lambda_{I,t+1}(1-\delta_H) q_{t+1}^H\right]. \tag{18}$$

The remaining FOC are standard. They are reported in Gomes, Jacquinot and Pisani (2010, 2012).

Impatient household ("borrower")

Utility. The representative impatient household represents a fraction ω_J of the H population. Her discount factor is smaller than those of the patient household and the bank. This makes her, in equilibrium, borrower *vis-à-vis* the domestic bank. The impatient household lifetime utility function is:

$$E_t\left[\sum_{k=0}^{\infty}(\beta_J)^k \left(\frac{1-\kappa}{1-\sigma}\left(\frac{C_{J,t+k} - \kappa C_{J,t+k-1}}{1-\kappa}\right)^{1-\sigma} + \iota_J \ln H_{J,t+k} - \frac{1}{1+\zeta} N_{J,t+k}^{1+\zeta}\right)\right], \tag{19}$$

where $0 < \beta_J < \beta_I < 1$ and consumption is subject to external habit.

Budget constraint. The impatient household provides work to firms in the two intermediate goods production sectors under monopolistic competition and sets wages $W_{J,t}$ in a staggered way, *à la* Calvo (1983) with indexation.[14] She gets *lump-sum* transfers from the domestic government, TR_J/ω_J, where TR_J are aggregate nominal transfers. The (nominal) budget constraint is:

$$\begin{aligned} B_{J,t} - R_{t-1}^L B_{J,t-1} &= (1-\tau_{N,t} - \tau_{WH,t}) W_{J,t} N_{J,t} \\ &- (1+\tau_{C,t}) P_t^C C_{J,t} - Q_t^H (H_{J,t} - (1-\delta_H) H_{J,t-1}) - P_t^C \Gamma_{B_J,t} + \frac{TR_J}{\omega_J} \end{aligned} \tag{20}$$

[14] For details see Gomes, Jacquinot and Pisani (2010, 2012).

where $B_{J,t} < 0$ is the amount of loans from domestic bank and R_t^L is the interest rate, and Γ_{B_J} is the "real" adjustment cost on changing the borrowing position,

$$\Gamma_{B_J,t} \equiv \frac{\gamma_{B_J}}{2}\left(\frac{b_{J,t}}{b_{J,t-1}} - 1\right)^2, \tag{21}$$

with $\gamma_{B_J} > 0$ and $b_{J,t} \equiv \frac{B_{J,t}}{P_t^C}$.

Borrowing constraint. To borrow funds, the household needs collateral, represented by the expected value of her housing stock. Therefore, she faces the following borrowing constraint

$$-B_{J,t}R_t^L \leq -\rho_{B_J}\overline{\Pi}B_{J,t-1}R_{t-1}^L + (1-\rho_{B_J})\,V_{J,t}E_t\left[Q_{t+1}^H H_{J,t}\right], \tag{22}$$

where $0 < \rho_{B_J} < 1$ is a parameter capturing inertia in changing the borrowing limit as in Iacoviello (2015), $\overline{\Pi}$ is the steady-state inflation (needed to properly calibrate the steady-state debt and, at the same time, satisfy the borrowing constraint) and $0 < V_{J,t} < 1$ is the (possibly time-varying) LTV ratio. The borrowing constraint is consistent with standard lending criteria used in the mortgage market, which limit the amount lent to a fraction of the value of the asset.

FOC. The impatient household maximizes utility with respect to consumption of nondurables, housing and loans subject to the budget constraint and the borrowing constraint and taking all prices, but wages, as given. The reason is that the impatient household supplies labor under monopolistic competition. Thus, she optimally sets her nominal wage taking labor demand by firms into account. The borrowing constraint holds with equality (see Iacoviello, 2005). The household' consumption is subject to external habit formation. All nominal variables in the budget constraint and in the borrowing constraint are expressed in "real" terms by dividing them by the consumption price deflator P_t^C.

Focusing on the new features of the model, we obtain the following FOC:

- marginal utility of consumption of nondurable goods $\Lambda_{J,t}$

$$\Lambda_{J,t}(1+\tau_C) = \left(\frac{C_{J,t} - \kappa C_{J,t-1}}{1-\kappa}\right)^{-\sigma}; \tag{23}$$

- loans demand

$$\begin{aligned}
\Lambda_{J,t} \quad &= \quad \beta_J E_t\left[\Lambda_{J,t+1}R_t^L\Pi_{C,t+1}^{-1}\right] \\
&- \quad \gamma_{B_J}\Lambda_{J,t}\left(\frac{b_{J,t}}{b_{J,t-1}} - 1\right)\frac{1}{b_{J,t-1}} + \beta_J\gamma_{B_J}E_t\left[\Lambda_{J,t+1}\left(\frac{b_{J,t+1}}{b_{J,t}} - 1\right)\frac{b_{J,t+1}}{b_{J,t}^2}\right] \\
&+ \quad R_t^L\Lambda_{JC,t} - \rho_{B_J}\overline{\Pi}\beta_J E_t\left[\Lambda_{JC,t+1}R_t^L\Pi_{C,t+1}^{-1}\right];
\end{aligned} \tag{24}$$

- real estate demand

$$\Lambda_{J,t} q_t^H = \frac{\iota_J}{H_{J,t}} + \beta_J E_t \left[\Lambda_{J,t+1}(1-\delta_H) q_{t+1}^H\right] + (1-\rho_{B_J})\, \Lambda_{JC,t} V_{J,t} E_t \left[q_{t+1}^H \Pi_{C,t+1}\right], \quad (25)$$

where $\Lambda_{JC,t}$ is the Lagrange multiplier of the borrowing constraint. The borrowing constraint affects the optimal choices of borrowing and housing services (equations 24 and 25, respectively). The multiplier equals the increase in lifetime utility that would stem from borrowing R_t^L euros, consuming or investing the proceeds, and reducing consumption by an appropriate amount the following period.

2.3 Entrepreneur

Utility. The representative entrepreneur represents a fraction ω_E of the H population. She maximizes lifetime utility represented by

$$E_t \sum_{k=0}^{\infty} (\beta_E)^k \left(\frac{1-\kappa}{1-\sigma} \left(\frac{C_{E,t+k} - \kappa C_{E,t+k-1}}{1-\kappa} \right)^{1-\sigma} \right), \quad (26)$$

where consumption of nondurable goods is subject to external habit.

Budget constraint. The entrepreneur owns the physical capital stock and part of the aggregate domestic stock of real estate. Both are rented in a competitive market to firms operating in the domestic intermediate sectors. Entrepreneurs can borrow funds from domestic banks. The investment in physical capital is subject to adjustment costs. The budget constraint reads as

$$\begin{aligned} B_{E,t} - R_{t-1}^L B_{E,t-1} &= R_{H,t} H_{E,t-1} + (1-\tau_{K,t}) \left(R_{K,t} u_t - \Gamma_{u,t} P_t^I \right) K_{E,t-1} + \tau_{K,t} \delta_K P_t^I K_{E,t} \\ &- Q_t^H \left(H_{E,t} - (1-\delta_H) H_{E,t-1} \right) - (1+\tau_{C,t})\, P_t^C C_{E,t} - P_t^I I_{E,t} \\ &- P_t^C \Gamma_{B_E,t}, \end{aligned} \quad (27)$$

where $B_{E,t} < 0$ is the amount of loans from domestic bank, $R_{H,t}$ and $R_{K,t}$ are the rental rates of real estate $H_{E,t}$ and physical capital $K_{E,t}$ to firms in the intermediate sector, respectively. The variable u_t stands for capital utilization and $\Gamma_{u,t}$ stands for the corresponding adjustment cost. The variable $0 < \tau_{K,t} < 1$ is the tax rate on physical capital, set by the domestic fiscal authority. The parameters $0 < \delta_K, \delta_H < 1$ are the depreciation rates of capital and real estate, respectively. The variable $I_{E,t}$ is the investment in physical capital, whose price is P_t^I. The term Γ_{B_E} represents the "real" adjustment cost on changing the borrowing position, defined as

$$\Gamma_{B_E}, t \equiv \frac{\gamma_{B_E}}{2} \left(\frac{b_{E,t}}{b_{E,t-1}} - 1 \right)^2, \quad (28)$$

with $\gamma_{B_E} > 0$ and $b_{E,t} \equiv \frac{B_{E,t}}{P_t^C}$.

Investment is subject to adjustment costs, namely

$$K_{E,t} = (1 - \delta_K) K_{E,t-1} + (1 - \Gamma_{I,t}) I_{E,t}, \tag{29}$$

where $\Gamma_{I,t}$ is the adjustment cost formulated in terms of changes in investment:

$$\Gamma_{I,t} \equiv \frac{\gamma_I}{2} \left(\frac{I_{E,t}}{I_{E,t-1}} - 1 \right)^2, \tag{30}$$

with $\gamma_I > 0$.

Borrowing constraint. The entrepreneur borrows funds $B_{E,t}$ from the domestic banking sector using the owned real estate and physical capital as collateral:

$$-R_t^L B_{E,t} \leq -\rho_{B_E} \overline{\Pi} B_{E,t-1} R_{t-1}^L + (1 - \rho_{B_E}) V_{H_E,t} E_t \left[Q_{t+1}^H H_{E,t} \right] + (1 - \rho_{B_E}) V_{K_E,t} E_t \left[Q_{t+1}^K K_{E,t} \right], \tag{31}$$

where $0 < \rho_{B_E} < 1$ is a parameter that captures inertia in changing the borrowing position and $0 < V_{H_E,t}, V_{K_E,t} < 1$ are the (possibly time-varying) entrepreneur's LTV ratios associated with real estate and physical capital, respectively. Finally, Q^K is the Tobin's Q, i.e. the price of capital, which is different from one because of the adjustment costs on investment change.

FOC. The entrepreneur maximizes her utility with respect to consumption of nondurables goods, investment in physical capital, physical capital, and housing, subject to the budget constraint and the borrowing constraint, and taking prices as given. All nominal variables in the budget constraint and in the borrowing constraint are expressed in "real" terms by dividing them by the consumption price deflator P_t^C. In particular, $p_t^I \equiv P_t^I / P_t^C$, $r_{H,t} \equiv R_{H,t}/P_t^C$, $r_{K,t} \equiv R_{K,t}/P_t^C$, $q_t^K \equiv Q_t^K / P_t^C$. The FOC related to EAGLE-FLI novel features are:

- consumption of nondurable goods

$$\Lambda_{E,t}(1 + \tau_{C,t}) = \left(\frac{C_{E,t} - \kappa C_{E,t-1}}{1 - \kappa} \right)^{-\sigma}; \tag{32}$$

- investment in physical capital

$$\begin{aligned} p_t^I &= q_t^K \left(1 - \Gamma_{I,t} - \Gamma'_{I,t} I_{E,t} \right) \\ &\quad + \beta_E E_t \left[\frac{\Lambda_{E,t+1}}{\Lambda_{E,t}} q_{t+1}^K \Gamma'_{I,t+1} \frac{I_{E,t+1}^2}{I_{E,t}} \right]; \end{aligned} \tag{33}$$

- physical capital demand

$$
\begin{aligned}
\Lambda_{E,t} q_t^K &= \beta_E E_t \left[\Lambda_{E,t+1} \left(1 - \tau_{K,t}\right) \left(r_{K,t+1} u_{t+1} - \Gamma_{u,t+1} p_{t+1}^I \right) \right] + \tau_{K,t} \delta_K p_t^I \\
&+ \beta_E E_t \left[\Lambda_{E,t+1} q_{t+1}^K (1 - \delta_H) \right] + \left(1 - \rho_{B_E}\right) \Lambda_{EC,t} V_{K_E,t} E_t \left[q_{t+1}^K \Pi_{C,t+1} \right]; \quad (34)
\end{aligned}
$$

- real estate demand

$$
\Lambda_{E,t} q_t^H = \beta_E E_t \left[\Lambda_{E,t+1} r_{H,t+1} + \Lambda_{E,t+1} (1 - \delta_H) q_{t+1}^H \right] + \left(1 - \rho_{B_E}\right) \Lambda_{EC,t} V_{H_E,t} E_t \left[q_{t+1}^H \Pi_{C,t+1} \right]; \quad (35)
$$

- loans demand

$$
\begin{aligned}
\Lambda_{E,t} &= \beta_E E_t \left[\Lambda_{E,t+1} R_t^L \Pi_{C,t+1}^{-1} \right] \\
&- \gamma_{B_E} \Lambda_{E,t} \left(\frac{b_{E,t}}{b_{E,t-1}} - 1 \right) \frac{1}{b_{E,t-1}} + \beta_E \gamma_{B_E} E_t \left[\Lambda_{E,t+1} \left(\frac{b_{E,t+1}}{b_{E,t}} - 1 \right) \frac{b_{E,t+1}}{b_{E,t}^2} \right] \\
&+ \Lambda_{EC,t} R_t^L + \beta_E \rho_{B_E} \overline{\Pi} E_t \left[\Lambda_{EC,t+1} R_t^L \Pi_{C,t+1}^{-1} \right], \quad (36)
\end{aligned}
$$

where $\Lambda_{E,t}$ is the Lagrange multiplier of the entrepreneurs' budget constraint and $\Lambda_{EC,t}$ is the Lagrange multiplier of the entrepreneurs' borrowing constraint. Like for impatient households, the equations for consumption and housing choice hold with the addition of the multiplier associated with the borrowing restriction. The borrowing constraint introduces a wedge between the price of the real estate and its rental rate. It can be considered as a tax on the demand for credit and for real estate.

2.4 Firms

There are two types of firms. One type produces intermediate goods, either internationally tradable or nontradable. The other type produces nontradable final goods for consumption and investment purposes, using all intermediate goods as inputs.

Final good firms

Firms producing final nontradable goods are symmetric, act under perfect competition and use nontradable as well as domestic and imported tradable intermediate goods as inputs. The size of the sector is s^H. The intermediate goods are assembled according to a constant elasticity of substitution (CES) technology. Final goods can be used both for private consumption and investment. The setup of the final good firms mimics the one in the version of the EAGLE model without financial frictions and a banking sector (see Gomes, Jacquinot and Pisani 2010, 2012).

Intermediate good firms

There are firms producing tradable and nontradable intermediate goods (brands) under a monopolistic competition regime. Each tradable brand is produced by a firm h belonging to the continuum of mass s^H $\left(h \in \left[0, s^H\right)\right)$. Similarly, each nontradable brand is produced by a firm n, defined over the continuum of mass s^N $\left(n \in \left[0, s^H\right)\right)$. Since the EAGLE-FLI model introduces a new input in production compared to the original EAGLE model, we will describe the intermediate goods sector setup in more detail.

Production technology. Each nontradable and tradable intermediate good, respectively n and h, is produced using a Cobb-Douglas technology with three inputs: physical capital rented from domestic entrepreneurs ($K_t^D(n)$ and $K_t^D(h)$); domestic labor ($N_t^D(n)$ and $N_t^D(h)$, each being an aggregate of both patient and impatient households labor services); real estate ($H_t^D(n)$ and $H_t^D(h)$) rented from domestic entrepreneurs

$$Y_t^{S,N} = z_{N,t}\left(K_t^D\right)^{\alpha_{KN}}\left(H_t^D\right)^{\alpha_{HN}}\left(N_t^D\right)^{1-\alpha_{KN}-\alpha_{HN}}, \quad (37)$$

$$Y_t^{S,T} = z_{T,t}\left(K_t^D\right)^{\alpha_{KT}}\left(H_t^D\right)^{\alpha_{HT}}\left(N_t^D\right)^{1-\alpha_{KT}-\alpha_{HT}}, \quad (38)$$

where $\alpha_{KN}, \alpha_{KT}, \alpha_{HN}, \alpha_{HT} > 0$, $\alpha_{KT} + \alpha_{HT} < 1$, and $\alpha_{KN} + \alpha_{HN} < 1$. $z_{N,t}$ and $z_{T,t}$ are sector-specific productivity shocks (they are identical across firms within each sector).[15]

Taking input prices as given, firms in each sector minimize total production costs subject to the respective production function (equations 37 and 38). This yields standard demand functions for each type of input (see the Technical Appendix). Finally, the labor bundle of the generic firm n in the nontradables sector is defined as

$$N_t^D(n) = \left[\left(\frac{1-\omega_J-\omega_E-\omega_B}{1-\omega_E-\omega_B}\right)^{\frac{1}{\eta}} N_{I,t}^D(n)^{\frac{\eta-1}{\eta}} + \left(\frac{\omega_J}{1-\omega_E-\omega_B}\right)^{\frac{1}{\eta}} N_{J,t}^D(n)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \quad (39)$$

where $\eta > 0$ is the elasticity of substitution between the two household-specific labor bundles, $N_{I,t}^D(n)$ and $N_{J,t}^D(n)$. This yields the following demand functions:

$$N_{I,t}^D(n) = \frac{1-\omega_J-\omega_E-\omega_B}{1-\omega_E-\omega_B}\left(\frac{W_{I,t}}{W_t}\right)^{-\eta} N_t^D(n), \quad (40)$$

$$N_{J,t}^D(n) = \frac{\omega_J}{1-\omega_E-\omega_B}\left(\frac{W_{J,t}}{W_t}\right)^{-\eta} N_t^D(n), \quad (41)$$

where W_t is

$$W_t = \left[\left(\frac{1-\omega_J-\omega_E-\omega_B}{1-\omega_E-\omega_B}\right) W_{I,t}^{1-\eta} + \left(\frac{\omega_J}{1-\omega_E-\omega_B}\right) W_{J,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}. \quad (42)$$

[15] In the case of the EA there is also a technology shock z_t, which is common to both sectors and regions.

Similar bundles and demand functions hold for firms in the tradables sector.

Price setting. Each firm sells its differentiated output under monopolistic competition. The firm producing the tradable intermediate good charges different prices in local currency at home and in each foreign region. There is sluggish price adjustment due to staggered price contracts *à la* Calvo (1983). Firm h in the intermediate tradables sector discriminates across countries, by invoicing and setting the price of its brand in the currency of the generic destination market. Hence, the local currency pricing assumption holds. For details on the price setting equations see Gomes, Jacquinot and Pisani (2010, 2012).

2.5 Monetary authority

In the case of the EA, there exists a single monetary authority that targets a weighted (by regional size) average of regional (Home, H, and REA) annual consumer price inflation and real quarterly output growth:

$$\begin{aligned}\left(R_t^{EA}\right)^4 &= \phi_R^{EA}\left(R_{t-1}^{EA}\right)^4 + \left(1-\phi_R^{EA}\right)\left[\left(\overline{R}^{EA}\right)^4 + \phi_\Pi^{EA}\left(\Pi_{C,t}^{EA,4} - \overline{\Pi}^{EA,4}\right)\right] \\ &\quad + \phi_{gY}^{EA}\left(Y_{gr,t}^{EA} - 1\right) + \varepsilon_{R,t}^{EA}, \end{aligned} \tag{43}$$

where $\overline{\Pi}^{EA,4}$ is the long-run (yearly) inflation target and the yearly inflation rate $\Pi_{C,t}^{EA,4}$ is defined as

$$\Pi_{C,t}^{EA,4} \equiv \left(\Pi_{C,t}^{H,4}\right)^{\frac{s^H}{s^H+s^{REA}}}\left(\Pi_{C,t}^{REA,4}\right)^{\frac{s^{REA}}{s^H+s^{REA}}}, \tag{44}$$

with

$$\Pi_{C,t}^{H,4} \equiv \frac{P_{C,t}^H}{P_{C,t-4}^H},\ \ \Pi_{C,t}^{REA,4} \equiv \frac{P_{C,t}^{REA}}{P_{C,t-4}^{REA}}, \tag{45}$$

and the EA output growth rate $Y_{gr,t}^{EA}$ is defined as

$$Y_{gr,t}^{EA} \equiv \frac{Y_t^{EA}}{Y_{t-1}^{EA}} \equiv \frac{s^H Y_t^H + s^{REA} Y_t^{REA}}{s^H Y_{t-1}^H + s^{REA} Y_{t-1}^{REA}}, \tag{46}$$

where Y_t^H and Y_t^{REA} represent *per capita* total final real output in the H and REA regions, respectively. They are weighted by the corresponding regional sizes in the world economy.

2.6 Market clearing conditions

In this section, we report clearing conditions for the housing, loans, deposits, EA cross-country interbank markets.

- **Housing market.** Households and entrepreneurs demand real estate, which is assumed to be nontradable across countries and in fixed (per capita) aggregate supply $\bar{H}$

$$(1-\omega_J-\omega_E-\omega_B)H_{I,t}+\omega_J H_{J,t}+\omega_E H_{E,t}=\bar{H}. \tag{47}$$

Entrepreneurs rent housing to firms producing intermediate tradable and nontradable goods:

$$H_t^T+H_t^{NT}=\omega_E H_{E,t}, \tag{48}$$

where

$$H_t^T=\frac{1}{s^H}\int_0^{s^H}H_t^D(h)dh,\ \ H_t^N=\frac{1}{s^H}\int_0^{s^H}H_t^D(n)dn. \tag{49}$$

- **Loans market.** Bankers supply loans to domestic entrepreneurs and impatient households:

$$\omega_B L_t+\omega_J B_{J,t}+\omega_E B_{E,t}=0. \tag{50}$$

- **Deposits market**. Patient households demand bank deposits to domestic banks:

$$\omega_B D_t^{Supply}=(1-\omega_J-\omega_E-\omega_B)D_t^{Dem}. \tag{51}$$

- **EA cross-country interbank market.** The two EA regional banks lend each other resources through the EA interbank market. The market clearing is:

$$s^H\omega_B^H L_t^{IB,H}+s^{REA}\omega_B^{REA}L_t^{IB,REA}=0, \tag{52}$$

where $L_t^{IB,H}$ and $L_t^{IB,REA}$ are the positions of Home and REA regions, respectively.

2.7 Net foreign asset position and international relative prices

Home holdings of foreign bonds *per capita* (that is, the Home economy's net foreign asset position in *per capita* terms), denominated in US dollars, evolve according to

$$\begin{aligned}(1-\omega_J-\omega_E-\omega_B)B_{US,t}+\omega_B\frac{L_t^{IB}}{S_t^{H,US}}+(1-\omega_J-\omega_E-\omega_B)\frac{B_{I,t}^{EA}}{S_t^{H,US}}=\\ (1-\omega_J-\omega_E-\omega_B)B_{US,t-1}R_{t-1}^{US}+\omega_B\frac{L_{t-1}^{IB}R_{t-1}^{IB}}{S_t^{H,US}}\\ +(1-\omega_J-\omega_E-\omega_B)\frac{B_{I,t-1}^{EA}R_{t-1}}{S_t^{H,US}}+\frac{TB_t^H}{S_t^{H,US}},\end{aligned} \tag{53}$$

where TB_t^H stands for Home trade balance *per capita*, defined as

$$TB_t^H\equiv\sum_{CO\neq H}\frac{s^{CO}}{s^H}S_t^{H,CO}P_{X,t}^{H,CO}IM_t^{CO,H}-\sum_{CO\neq H}P_{IM,t}^{H,CO}IM_t^{H,CO}, \tag{54}$$

where $S_t^{H,CO}$ is the bilateral nominal exchange rate of the Home country relative to country CO (euro *per* unit of country CO currency), $IM_t^{CO,H}$ is Home exports ($P_{X,t}^{H,CO}$ is the corresponding price index in foreign currency), $IM_t^{H,CO}$ is Home imports ($P_{IM,t}^{H,CO}$ is the corresponding price index in euro terms).

The market clearing conditions, jointly with the budget constraints of the households, entrepreneurs, banking sector and the fiscal authority, imply the following resource constraint in *per capita* terms

$$\begin{aligned} P_{Y,t}Y_t &= P_{C,t}C_t + P_{I,t}\left(I_t + \Gamma_{u,t}K_t\right) + P_{G,t}G_t + \sum_{CO\neq H} \frac{s^{CO}}{s^H} S_t^{H,CO} P_{X,t}^{H,CO} IM_t^{CO,H} \\ &- \sum_{CO\neq H} P_{IM,t}^{H,CO} \left(IM_{C,t}^{H,CO} \frac{1-\Gamma_{IM^C}^{H,CO}}{\Gamma_{IM^C}^{H,CO\dagger}} \right) \\ &- \sum_{CO\neq H} P_{IM,t}^{H,CO} \left(IM_{I,t}^{H,CO} \frac{1-\Gamma_{IM^I}^{H,CO}}{\Gamma_{IM^I}^{H,CO\dagger}} \right), \end{aligned} \tag{55}$$

where G_t is public consumption and $P_{G,t}$ the corresponding price deflator, and consumption in *per capita* terms, C_t, is

$$C_t \equiv \omega_B C_{B,t} + (1-\omega_J-\omega_E-\omega_B)C_{I,t} + \omega_J C_{J,t} + \omega_E C_{E,t}, \tag{56}$$

$$C_{B,t} \equiv \frac{DIV_t^B}{P_t^C}, \tag{57}$$

and

$$I_t \equiv \omega_E I_{E,t}, \tag{58}$$

$$K_t \equiv \omega_E K_{E,t}, \tag{59}$$

and $\Gamma_{IM^C}^{H,CO}$ is a (standard) adjustment costs on imports and $\Gamma_{IM^C}^{H,CO\dagger}$ is defined as[16]

$$\Gamma_{IM^C}^{H,CO\dagger} \equiv 1 - \Gamma_{IM^C}^{H,CO}\left(\frac{IM_t^{C,CO}}{Q_t^C}\right) - \left(\Gamma_{IM^C}^{H,CO}\left(\frac{IM_t^{C,CO}}{Q_t^C}\right)\right)' IM_t^C.$$

The Home bilateral terms of trade relative to the generic country CO are defined as the Home price of imports relative to the price of Home exports, both expressed in Home currency:

$$TOT_t^{H,CO} \equiv \frac{P_{IM,t}^{H,CO}}{S_t^{H,CO} P_{X,t}^{H,CO}}. \tag{60}$$

The Home bilateral real exchange rate relative to the generic country CO is defined as the CPI

[16]See Gomes, Jacquinot and Pisani (2010) for more details.

of country CO relative to the CPI of country H, both expressed in Home currency:

$$RER_t^{H,CO} \equiv \frac{S_t^{H,CO} P_{C,t}^{CO}}{P_{C,t}^{H}}. \tag{61}$$

3 Calibration

We calibrate at the quarterly frequency the model blocs to Germany (Home country, as in the standard EAGLE), REA, US and RW. We set a subset of model parameters to match the (usual) "great" ratios and the banking variables (as a ratio to GDP). The remaining parameters are calibrated in line with the literature, in particular with the calibration of models such as EAGLE, GEM and NAWM.

Table 1 reports banks' balance sheet, as a ratio to annualized GDP. The data is taken from Eurostat Annual Sector Accounts and the Federal Reserve Board Financial Accounts (and refer to nominal outstanding amounts at the end of the year divided by annual nominal GDP). Given the lack of available data on collateralized loans for other purposes but housing, we choose to match the average share (over the 1999-2013 period) of total loans to households, namely to 64% for Germany; 61% for the REA; 90% for the US; 76% for the RW. We assume that the steady-state (EA) interbank position is zero. Given the matched values for loans to households, the assumed interbank position, the assumed zero excess bank capital in the steady state, the calibration of the capital requirement and the entrepreneurs' LTV ratios (see below), we allow deposits to endogenously adjust consistently with the bank's balance sheet. This calibration strategy emphasizes the role of bank's loans and thus induces a broad interpretation of bank deposits (given the absence of other financing sources such as bank bonds in the model).

Table 2 reports the matched great ratios. National accounts data for the EA regions and the US are taken from Eurostat. We set region sizes to match the share of world GDP (IMF data). The sources of EA and of US net foreign asset position data are Eurostat and Bureau of Economic Analysis, respectively.[17]

Table 3 reports the parameters related to financial frictions and banking sector. The impatient households' LTV ratio is set to 0.7 in both EA regions, in line with the calibration of the EA households LTV ratio in Lombardo and McAdam (2012) and the calibration of Calza, Monacelli and Stracca (2013) for Germany. The entrepreneurs' LTV ratio associated with housing as collateral is also set to 0.7, while the LTV ratio associated with capital is set to 0.30, in line with the literature. Both adjustment costs on excess bank capital and on the EA interbank position are set to 0.001 in all blocs. The adjustment cost on deposits is set to 0.0001. We set adjustment costs to a rather low value to limit their role for the dynamics of the model, while, at the same time, preserving the model stationarity. As for the adjustment costs on changes in loans, we set the corresponding parameters both for the banks and the borrowers (impatient households and

[17]Given the import shares, net foreign asset position and international interest rate, the steady-state trade balance and real exchange rate level endogenously adjust. The RW is obtained as a residual.

entrepreneurs) to 1.5. Finally, the capital requirement parameter is set to 8% in the EA and the US, consistent with the BASEL III minimum requirement for total capital.

Table 4 reports population shares, preference and technology parameters. The share of patient households in each region is set to 30%, the share of impatient households to 0.50 while the share of entrepreneurs is set to 0.10 (as reported in Table 3, the share of bankers is set to 10%).

Preferences are assumed to be the same across household types and regions. We set the discount factor of patient households to 0.9926 (implying a steady-state annualized real interest rate of about 3%). The discount factor of impatient households, entrepreneurs and bankers (the latter is reported in Table 3) are set to 0.96, 0.99 and 0.9926, respectively.[18] The habit persistence parameter, the intertemporal elasticity of substitution and the Frisch elasticity are respectively set to 0.70, 1 and 0.50. We set quarterly depreciation rate of capital to be consistent with a 10% annual depreciation rate. The annual depreciation rate for the housing stock is set at a lower value than that for capital, to 4%.

On the production side, in the Cobb-Douglas production functions of tradable and nontradable intermediate goods the bias towards capital is set to around 0.30 and the bias towards housing to 0.01 in both tradable and nontradable sectors. As for the final goods baskets, the degree of substitutability between domestic and imported tradables is higher than that between tradables and nontradables, consistent with existing literature (elasticities equal to 2.5 and 0.5, respectively).[19] The biases towards the tradable bundle in the consumption and investment baskets are equal respectively to 0.45 and 0.75 in each region of the EA and respectively to 0.35 and 0.75 in the US and RW. The weight of domestic tradable goods in the consumption and investment tradable baskets is different across countries, to be coherent with multilateral import-to-GDP ratios.

Markups in the EA nontradables sector (a proxy for the services sector) and labor market are higher than the corresponding values in the US and RW (see Table 5). In all regions the markup in the tradables sector (a proxy for the manufacturing sector) has the same value and the markup in the nontradables sector is higher than that in the labor market.[20]

Table 6 reports nominal and real rigidities. We set Calvo price parameters in the domestic tradables and nontradables sector to 0.92 (12.5 quarters) in the EA, consistently with estimates by Christoffel, Coenen, and Warne (2008) and Smets and Wouters (2003). Corresponding nominal rigidities outside the EA are equal to 0.75, implying an average frequency of adjustment equal to 4 quarters, in line with Faruqee, Laxton, and Muir (2007). Calvo wage parameters and price

[18]Following Iacoviello (2015) a necessary condition for entrepreneurs to be constrained is that their discount factor is lower than the inverse of the return on loans. When this condition is satisfied entrepreneurs will be constrained in a neighborhood of the steady state. Similarly, banks are “credit-constrained” by their capital requirement (which holds as strict equality in a neighborhood of the steady state) as long as their discount factor is lower than the returns on deposits.

[19]Note that the short-run elasticity for imported goods is lower because of adjustment costs on imports. Numbers are consistent with Bayoumi, Laxton, and Pesenti (2004).

[20]The chosen values are consistent with estimates from Martins, Scarpetta and Pilat (1996), suggesting that the degree of competition in the nontradables sector is lower than in the tradables sector. Also, these values are in line with other similar studies, such as Bayoumi, Laxton, and Pesenti (2004), Faruqee, Laxton, and Muir (2007) and Everaert and Schule (2008).

parameters in the export sector are equal to 0.75 in all the regions. The indexation parameters on prices and wages are equal respectively to 0.50 and 0.75, so to get sufficiently hump-shaped response of wages and price. For real rigidities, we set adjustment costs on investment changes to 6 in the EA and to 4 in the case of the US and RW; and adjustment costs on consumption and investment imports to 2 and 1, respectively.

We set weights of bilateral imports on the bundles to match the trade matrix reported in Table 7.[21]

Table 8 reports parameters in the monetary policy rules and fiscal rules. The interest rate reacts to its lagged value (inertial component of the monetary policy), annual inflation and quarterly output growth. In the monetary union, monetary policy reacts to EA-wide variables. For fiscal rules, *lump-sum* taxes stabilize public debt. Steady-state ratios of government debt over output are equal to 2.40 in all the regions (0.6 in annual terms). Tax rates are set to be consistent with empirical evidence (see Coenen, McAdam, and Straub 2008).

4 Simulations

In what follows we report the effects of several shocks to show the main transmission channels operating in EAGLE-FLI. Specifically, we report a reduction in the EA monetary policy rate, an increase in the Home LTV ratio, an increase in the long-run amount of interbank lending by the Home bank, a simultaneous increase in the capital requirement ratio in both Home and REA regions. The model is simulated under perfect foresight using DYNARE.[22]

4.1 Reduction in the EA monetary policy rate

Figures 1a-1d show the implications of a monetary policy shock in the EA. The shock is such that there is an initial decline in the (annualized) short-term nominal interest rate of 25 basis points.

Figure 1a reports the response of the banking sector variables. Bank choices are dictated by the no-arbitrage conditions implicitly given by their FOC with respect to the different financial assets and liabilities. The decrease in the monetary policy rate is transmitted to interest rates on bank loans and bank deposits, that also decrease. Lending to domestic (impatient) households and entrepreneurs increases, financed by the increase in deposits (patient households smooth consumption, and thus increase their savings). Also, bank capital slightly falls. The Home bank decreases its lending to REA bank through the interbank market to a rather small extent.

Figure 1b reports the responses of borrowing and housing variables. In both regions, the impatient household and the entrepreneur increase their borrowing and their demand for housing, which they use as collateral. Higher demand by the impatient household and the entrepreneur

[21] The trade matrix is calibrated using Eurostat and IMF trade statistics.

[22] We report in the Technical Appendix new equations as they appear in the code, i.e. in real terms. Other equations are the same as in Gomes, Jacquinot and Pisani (2010), see the Appendix therein for details.

induces the increase in the housing price, which reinforces the impact of the shock by allowing higher borrowing against the housing stock. Firms operating in both the tradables and nontradables sectors increase their demand for rented housing as well, to increase production.

Figure 1c shows that the impact of the shock on main macroeconomic variables (GDP, GDP components and CPI inflation) is, as expected, expansionary. The consumption increase is in line with that of GDP while investment increases by more. The higher EA aggregate demand leads to an increase in imports. Exports also increase, favored by the depreciation of the real exchange rate.[23] The REA GDP increases slightly more than Home GDP does, as REA has a larger home bias than Home, i.e. a larger share of REA aggregate demand is satisfied by domestic production. Consistent with the lower home bias, Home imports increase more than REA imports, while Home exports increase more because of the larger increase in REA aggregate demand.

As reported in Figure 1d, consumption and labor by both types of households increase. Consumption of impatient households rises by a rather larger extent since the increase in house prices loosens the collateral constraint (despite the smaller unexpected rise in inflation). Real wages of impatient and patient households also increase, driven by the higher labor demand by domestic firms.

Spillovers to the US and the RW are rather small. To save on space, we do not report them.

Overall, the banking sector transmits the monetary policy stimulus to the real side of the economy, favoring an increase in EA economic activity. The impact of the common monetary policy shock is rather similar across the two EA regions.

4.2 Increase in REA LTV ratio

Figures 2a-2d show the effects of a change in lending standards applied by banks to their customers. This is simulated as an exogenous rise in the REA LTV ratio of impatient households and entrepreneurs (V_J and V_{H_E} in equations 22 and 31, respectively). In the initial period, the LTV ratios in the REA increase by 1 percentage point and subsequently gradually return to their steady-state values (the persistence of the shock process is set to 0.90).

Figure 2a shows the impact on bank related variables of the increase in the REA LTV ratio. Although this can be thought as a change in the policy that banks follow to extend their loans, it is akin to a shift in the demand schedule for loans, as it is encoded in the collateral constraint. The change allows REA impatient households and entrepreneurs to demand more loans at any given level of interest rates, since the LTV ratio has increased. The higher demand results in more loans being extended domestically at a higher interest rate. To finance the higher amount of loans, REA banks increase their demand for deposits and interbank borrowing (Home lending in the interbank market increases), bidding up the respective interest rates, while at the same time they start to increase their capital holdings, although gradually as it is relatively costly to deviate from the long-run value for bank capital.

[23] In all figures, an increase in the real exchange rate represents a depreciation.

As reported in Figure 2b, both impatient households and entrepreneurs increase the demand for real estate, driving up prices. The increase in the collateral value allows them to further increase their borrowing.

Figure 2c reports the effects on the main macroeconomic variables. REA GDP increases, driven by the increase in the domestic demand components. REA exports increase, as they benefit from the real exchange rate depreciation. REA imports increase as well, following the surge in Home aggregate demand.

Figure 2d shows that the increase in borrowing capacity stimulates, first and foremost, consumption of borrowers (both households and entrepreneurs). As the demand components rise, firms start to increase labour demand, pushing up real wages.

Spillovers to the Home bloc are small. Home banks increase their lending to REA banks through the cross-country interbank market. The additional lending is financed by raising domestic deposits, while lending to domestic firms and households and the bank capital do not greatly change. The Home GDP and CPI inflation essentially stay at their baseline levels. Given the small impact of the REA LTV shock on the Home economy, the union-wide GDP increases very modestly and inflation hardly changes. This implies that the EA monetary policy rate increases only slightly (as reported in Figure 2a).

4.3 Increase in Home banks lending in the interbank market

Figures 3a-3d show the implications of a very persistent increase in the amount of liquidity supplied by the Home banks in the (cross-country) interbank market. In this scenario, resources for consumption and investment available in one bloc of the EA (Home) are channeled to the other bloc (REA), via the interbank market. This is implemented by assuming that the long-run target of Home banks interbank lending, equal to zero in the steady state, increases on impact to 20 percentage points of steady-state GDP (see equation 4). The shock is temporary but very persistent, with an AR(1) coefficient equal to 0.995.

Figure 3a reports that the effects on bank variables. The interest rate in the interbank market is not greatly affected, as the increased supply of funds is immediately matched by increased demand. To finance the additional interbank loans, Home banks shift resources away from loans to domestic households and firms and, at the same time, increase demand for domestic deposits and, gradually, capital. In the other bloc, REA banks have now access to more resources and can increase their supply of domestic loans, inducing a fall in the interest rate on loans. They also correspondingly decrease their recourse to other sources of financing, such as deposits and bank capital.

Figure 3b shows the effects on borrowing and real estate of this resources reallocation across countries. Given the higher amount of loans to households and entrepreneurs, demand for real estate increases in the REA, inducing a surge in the REA real estate prices, which allows for more borrowing against the same housing stock, and thus amplifies the expansionary impact of the shock. The opposite happens in the Home country.

Similar cross-country asymmetric dynamics characterize the Home and REA macroeconomic aggregates (see Figures 3c-3d). The increase in REA loans favors REA aggregate demand, implying an increase in REA labor and driving up inflation in the REA region. To the opposite, the same variables decrease in the Home bloc.

4.4 Increase in the bank capital requirement

Figures 4a-4d report the responses to an unexpected permanent increase in the capital requirement implemented simultaneously in the two EA regions. The capital requirement Υ_K (see equation 6) is exogenously increased by 1 percentage point.

Figure 4a reports the responses of the main variables related to the banking sector. They are broadly similar across the two regions. Specifically, after the shock banks are under-capitalized with respect to the new level of regulatory requirement. Given the presence of adjustment cost on capital, banks increase the latter in a gradual manner to limit the tightening of loan supply. Loans to households and entrepreneurs are cut in a rather moderate way, cushioning almost all the shock on impact, while the corresponding interest rates are slightly bid up. As loans contract, there is a shrinkage in banks balance sheet that is matched on the funding side by a corresponding decrease in deposits demand by banks. The corresponding interest rate declines, albeit only modestly. Given the limited impact of the shock on economic activity and inflation, monetary policy is broadly unchanged.

We observe a modest flow of funds in the interbank market towards the Home country, which become a net borrower, and a sharp increase in the interest rate. The additional loans from the interbank market allow the Home bank to limit the shrinkage of its balance sheet.

Figure 4b shows the implication of the shock for the real estate. The fall in loans implies a reduction in real estate prices and an increase in patient households real estate holdings. As reported in Figure 4c, aggregate consumption and investment and, thus, GDP decrease; CPI inflation slightly falls as well.

Finally, Figure 4d shows that the lower aggregate demand implies a reduction in the demand for labour by firms, a fall in employment and real wages and a cut in labor income (which further depresses consumption).

Overall, the shock has rather mild recessionary (and similar) effects across countries. One important caveat applies to our results. As simulations are run under perfect foresight, we are not able to capture possible expansionary effects associated with the reduction in systemic risk, explained by the increase in bank capital. The expansionary effects can, at least partially, compensate the recessionary effect of lower loans. From this perspective, our results should be seen as an upper bound of the negative (and relatively small) effects of the increase in capital requirement on economic activity.

4.5 Sensitivity analysis

We show results obtained under alternative values of the households' and entrepreneurs' LTV ratios and the adjustment costs on the excess bank capital.[24]

Specifically, to further emphasize the role of financial frictions and the banking sector for the transmission mechanism of the shocks, we initially simulate an expansionary monetary policy shock (-25 annualized b.p.) when in both Home and REA regions the LTV ratios of households and entrepreneurs, V_J and V_{H_E} are set to 0.5 instead of 0.7 as in the benchmark calibration. Second, the increase in the capital requirement is simulated under a larger value of the bank capital adjustment cost in both Home and REA regions, set to 0.002 instead of 0.001.

Figure 5 reports the results for the monetary policy shock with a lower LTV ratio. Results do not qualitatively change but they do change quantitatively. GDP increases to a lower extent in correspondence of the smaller LTV ratio. Given the relatively low LTV ratio, households and firms can borrow to a lower extent for a given increase in the real estate price. Thus, households and firms increase their aggregate demand for consumption and investment in a more contained way. The expansionary effects of the monetary policy easing are less amplified.

Figure 6 reports the results for the increase in the capital requirement with a larger bank capital adjustment cost. Similarly to the previous case, results do not change qualitatively but they do change quantitatively. Larger adjustment costs on bank capital can be thought as a proxy for increased difficulties faced by banks in raising their capital. They imply that banks have to cut relatively more their loans to achieve the new capital target. Thus, borrowers reduce relatively more their aggregate demand. The GDP decreases to a larger extent than in the benchmark case.

Overall, the two simulations, that aim to be illustrative and do not pretend to replicate empirical evidence, suggest the financial frictions and banking sector can be both sources and amplification links of financial and nonfinancial shocks in a rather nontrivial way. Thus, the sensitivity analysis further supports the relevance of the two features for a proper assessment of policy measures aiming at stabilizing the economy or at permanently changing its structural aspects.

5 Conclusions

The recent financial crisis and the ensuing prolonged recessionary phase have put new emphasis on financial shocks and the role of banking and financial features, namely for the transmission of monetary policy. This paper has outlined the EAGLE-FLI model, aimed at analyzing these issues in a monetary union setting.

We have built EAGLE-FLI by including the following features in the original EAGLE model: a microfounded banking sector in each of the four regions of the model; multiple agents in each

[24] For similar exercises, see Pataracchia et al. (2013) and Kollmann, Enders and Muller (2011).

countries; an enriched financial structure, allowing not only for riskless bonds, but also for banking loans, deposits, and capital; and related, the cross-country financial structure comprehensive not only of riskless bonds, but also of a EA interbank market. The model is perturbed by various financial shocks (LTV ratio, amount of resources that banks lend in the interbank market in the long run, banks' capital requirement) that are crucial to assess the interaction between the real and financial sectors of the economy.

Overall, the large scale of the EAGLE-FLI model, jointly with its microfoundations, allows to properly analyze the macroeconomic implications of financial factors in the EA countries. Equivalently, EAGLE-FLI allows to conduct a quantitative analysis in a theoretically coherent and fully consistent model setup, clearly spelling out all the policy implications. The model simulations have highlighted the importance of financial variables as sources of the business cycle and also in the transmission of shocks. Nevertheless, the model can be improved along several dimensions, that can be crucial for further understanding the transmission of spillovers in the EA. For example, the financial structure can be further enriched by allowing for bonds having different maturities. Borrowing constraints can be made occasionally binding. Finally, and related, uncertainty and risk can be added by appropriately changing the solution algorithm. These issues and their policy implications constitute an exciting research agenda.

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Table 1: Steady-State Financial Accounts (Ratio to annual GDP, %)

	Home	REA	US	RW
Loans	122	119	148	146
Loans to households	64	61	90	76
Loans to entrepreneurs	58	58	58	70
Interbank	0.0	0.0	n.a.	n.a.
Deposits	112	109	137	134
Excess bank capital	0.0	0.0	0.0	0.0

Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Table 2: Steady-State National Accounts (Ratio to GDP, %)

	Home	REA	US	RW
Domestic demand				
Private consumption	64	62	66	61
Cons. patient households	29	25	36	36
Cons. impatient households	30	32	25	19
Private investment	17	17	17	21
Public consumption	20	20	16	18
Trade				
Imports (total)	38	26	15	11
Imports of consumption goods	26	19	11	6
Imports of investment goods	12	8	4	5
Net foreign assets (ratio to annual GDP)	23	-24	-18	13
Production				
Tradables	39	40	37	40
Nontradables	61	60	63	60
Labor	39	39	51	46
Share of World GDP	6	13	19	61

Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Table 3: Financial and Banks Parameters

	Home	REA	US	RW
Households LTV ratio (V_J)	0.7	0.7	0.7	0.7
Entrepreneurs LTV ratio (V_{H_E})	0.7	0.7	0.7	0.7
Entrepreneurs LTV ratio (V_{K_E})	0.3	0.3	0.3	0.3
Households Loans smoothing (ρ_{B_J})	0.4	0.4	0.4	0.4
Entrepreneurs loans smoothing (ρ_{B_E})	0.4	0.4	0.4	0.4
Capital requirement (Υ^K)	0.08	0.08	0.08	0.08
Banks discount factor (β_B)	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$
Banks share in the population (ω_B)	0.10	0.10	0.10	0.10
Adjustment costs				
Deposits (γ_{DH})	0.0001	0.0001	0.0001	0.0001
Excess bank capital (γ_X)	0.001	0.001	0.001	0.001
Interbank (γ_{IB})	0.001	n.a.	n.a	n.a
Loans - banks (γ_L)	1.5	1.5	1.5	1.5
Loans - impatient hous. (γ^{BJ})	1.5	1.5	1.5	1.5
Loans - entrepreneurs (γ^{BE})	1.5	1.5	1.5	1.5

Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Table 4: Households, Entrepreneurs and Firms Behavior

	Home	REA	US	RW
Share in the population				
Patient households (ω_I)	0.30	0.30	0.30	0.30
Impatient households (ω_J)	0.50	0.50	0.50	0.50
Entrepreneurs (ω_E)	0.10	0.10	0.10	0.10
Households and entrepreneurs				
Patient hous. discount factor (β_I)	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$
Imp. households discount factor (β_J)	0.96	0.96	0.96	0.96
Entrepreneurs discount factor (β_E)	0.99	0.99	0.99	0.99
Intertemporal elasticity of substitution (σ^{-1})	1.00	1.00	1.00	1.00
Inverse of the Frisch elasticity of labor (ζ)	2.00	2.00	2.00	2.00
Housing services (ι_I, ι_J)	0.10	0.10	0.10	0.10
Habit persistence (κ)	0.70	0.70	0.70	0.70
Capital depreciation rate(δ_K)	0.025	0.025	0.025	0.025
Housing depreciation rate(δ_H)	0.01	0.01	0.01	0.01
Intermediate-good firms (trad. and nontrad. sectors)				
Substitution btw. labor and capital	1.00	1.00	1.00	1.00
Bias towards capital - tradables (α_T)	0.30	0.30	0.30	0.30
Bias towards housing - tradables (α_{HT})	0.01	0.01	0.01	0.01
Bias towards capital - nontradables (α_N)	0.37	0.40	0.31	0.43
Bias towards housing - nontradables (α_{HN})	0.01	0.01	0.01	0.01
Substitution btw. I-type and J-type labor (η)	4.33	4.33	7.25	7.25
Final consumption-good firms				
Substitution btw. domestic and imported trad. goods (μ_{TC})	2.50	2.50	2.50	2.50
Bias towards domestic tradables goods (υ_{TC})	0.04	0.36	0.50	0.69
Substitution btw. tradables and nontradables (μ_C)	0.50	0.50	0.50	0.50
Bias towards tradable goods (υ_C)	0.45	0.45	0.35	0.35
Substitution btw. consumption good imports (μ_{IMC})	2.50	2.50	2.50	2.50
Final investment-good firms				
Substitution btw. domestic and imported trad. goods (μ_{TI})	2.50	2.50	2.50	2.50
Bias towards domestic tradables goods (υ_{TI})	0.03	0.48	0.66	0.67
Substitution btw. tradables and nontradables (μ_I)	0.50	0.50	0.50	0.50
Bias towards tradable goods (υ_I)	0.75	0.75	0.75	0.75
Substitution btw. investment good imports (μ_{IMI})	2.50	2.50	2.50	2.50

Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Table 5: Price and Wage Markups (Implied Elasticities of Substitution)

	Tradables (θ_T)	Nontradables (θ_N)	Wages ($\eta_I = \eta_J$)
Home	1.20 (6.0)	1.50 (3.0)	1.30 (4.3)
REA	1.20 (6.0)	1.50 (3.0)	1.30 (4.3)
US	1.20 (6.0)	1.28 (4.6)	1.16 (7.3)
RW	1.20 (6.0)	1.28 (4.6)	1.16 (7.3)

Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Table 6: Real and Nominal Rigidities

	Home	REA	US	RW
Adjustment costs				
Imports of consumption goods (γ_{IM^C})	2.00	2.00	2.00	2.00
Imports of investment goods (γ_{IM^I})	1.00	1.00	1.00	1.00
Capital utilization (γ_{u2})	2000	2000	2000	2000
Investment (γ_I)	6.00	6.00	4.00	4.00
Intermediation cost function - USD bond (γ_{B^*})	0.01	0.01	...	0.01
Intermediation cost function - Euro bond ($\gamma_{B^{EA}}$)	...	0.01	...	...
Calvo parameters				
Wages - households I and J (ξ_I and ξ_J)	0.75	0.75	0.75	0.75
Prices - domestic tradables (ξ_H) and nontradables (ξ_N)	0.92	0.92	0.75	0.75
Prices - exports (ξ_X)	0.75	0.75	0.75	0.75
Degree of indexation				
Wages - households I and J (χ_I and χ_J)	0.75	0.75	0.75	0.75
Prices - domestic tradables (χ_H) and nontradables (χ_N)	0.50	0.50	0.50	0.50
Prices - exports (χ_X)	0.50	0.50	0.50	0.50

Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Table 7: International Linkages (Trade Matrix, Share of Domestic GDP, %)

	Home	REA	US	RW
Consumption-good imports				
Substitution btw. consumption good imports (μ_{IMC})	2.50	2.50	2.50	2.50
Total consumption good imports	25.7	18.7	11.0	6.1
From partner				
Home	-	4.0	0.4	1.3
REA	10.2	-	0.9	2.7
US	1.3	1.3	-	2.2
RW	14.3	13.5	9.7	-
Investment-good imports				
Substitution btw. investment good imports (μ_{IMI})	2.50	2.50	2.50	2.50
Total investment good imports	12.0	7.7	4.2	4.5
From partner				
Home	-	1.9	0.2	1.1
REA	4.1	-	0.3	1.3
US	1.3	1.2	-	2.1
RW	6.7	4.6	3.6	-

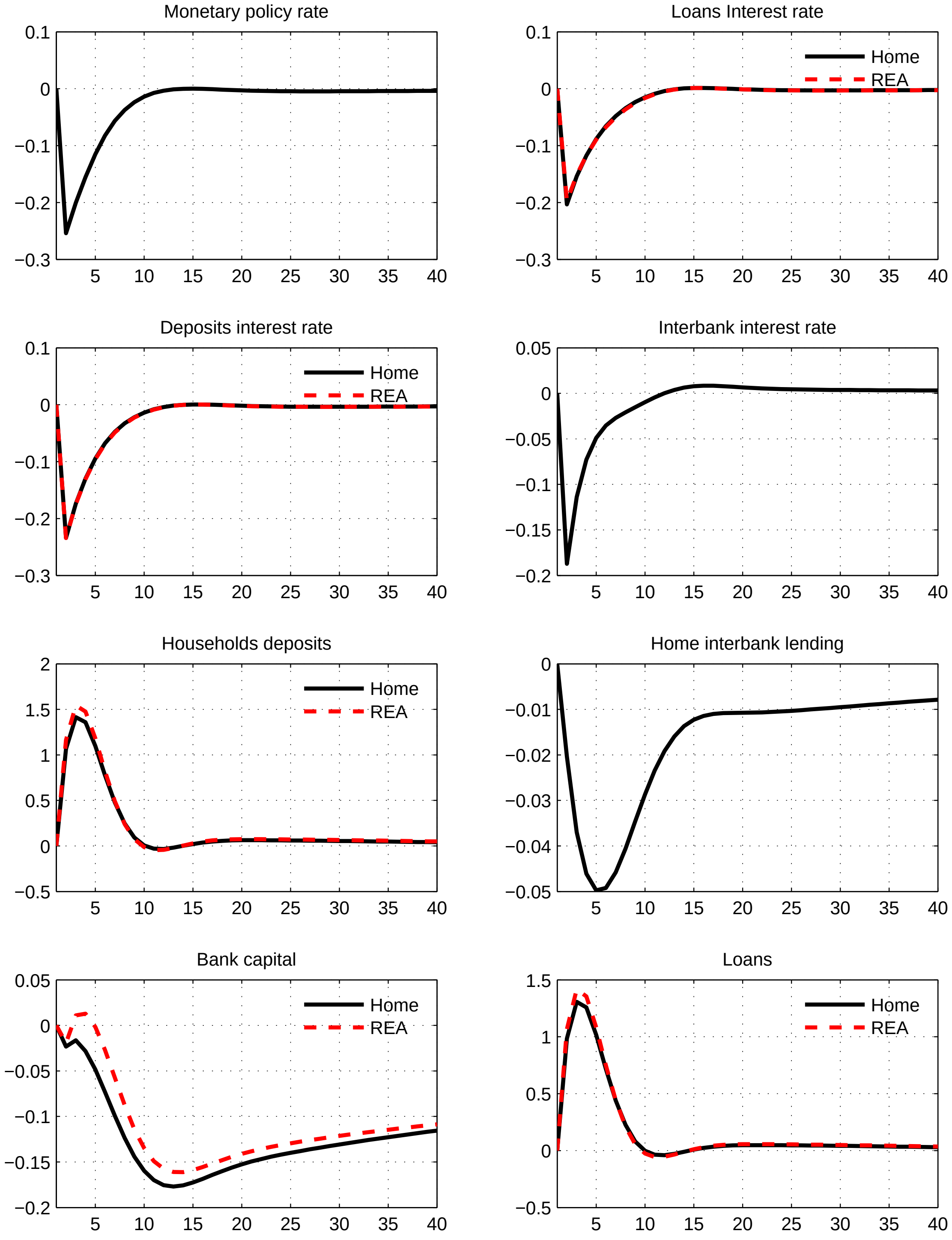
Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Table 8: Monetary and Fiscal Policy

	Home	REA	US	RW
Monetary authority				
Inflation target ($\overline{\Pi}^4$)	1.02	1.02	1.02	1.02
Interest rate inertia (ϕ_R)	0.87	0.87	0.87	0.87
Interest rate sensitivity to inflation gap (ϕ_Π)	1.70	1.70	1.70	1.70
Interest rate sensitivity to output growth (ϕ_Y)	0.10	0.10	0.10	0.10
Fiscal authority				
Government debt-to-output ratio ($\overline{B_Y}$)	2.40	2.40	2.40	2.40
Sensitivity of lump-sum taxes to debt-to-output ratio (ϕ_{B_Y})	5.00	5.00	5.00	5.00
Consumption tax rate (τ_C)	0.183	0.183	0.077	0.077
Dividend tax rate (τ_D)	0.00	0.00	0.00	0.00
Capital income tax rate (τ_K)	0.19	0.19	0.16	0.16
Labor income tax rate (τ_N)	0.122	0.122	0.154	0.154
Rate of social security contribution by firms (τ_{W_f})	0.219	0.219	0.071	0.071
Rate of social security contribution by households (τ_{W_h})	0.118	0.118	0.071	0.071

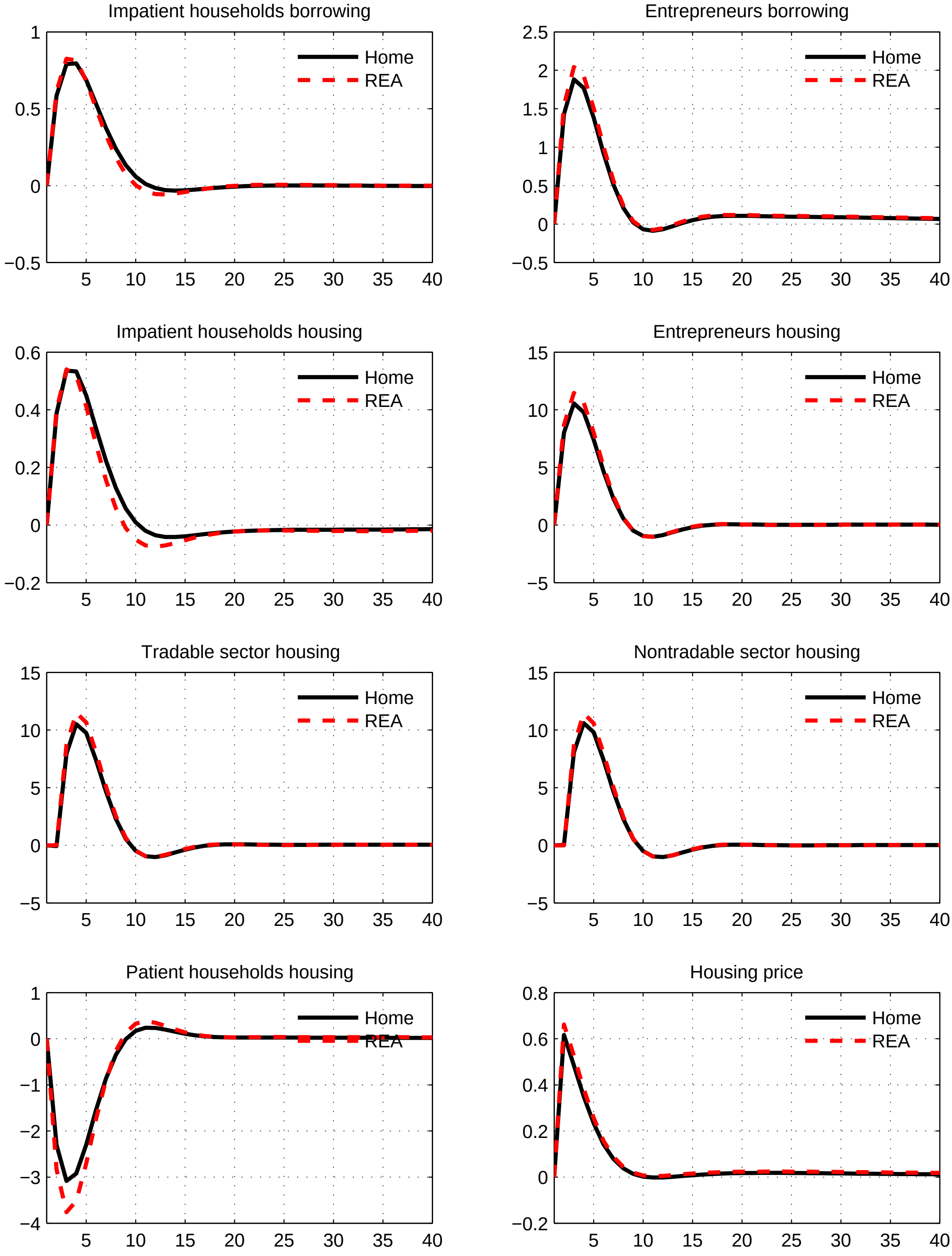
Note: REA=Rest of Euro Area; US=United States; RW=Rest of World

Figure 1a. Reduction in the EA interest rate – Effects on bank variables



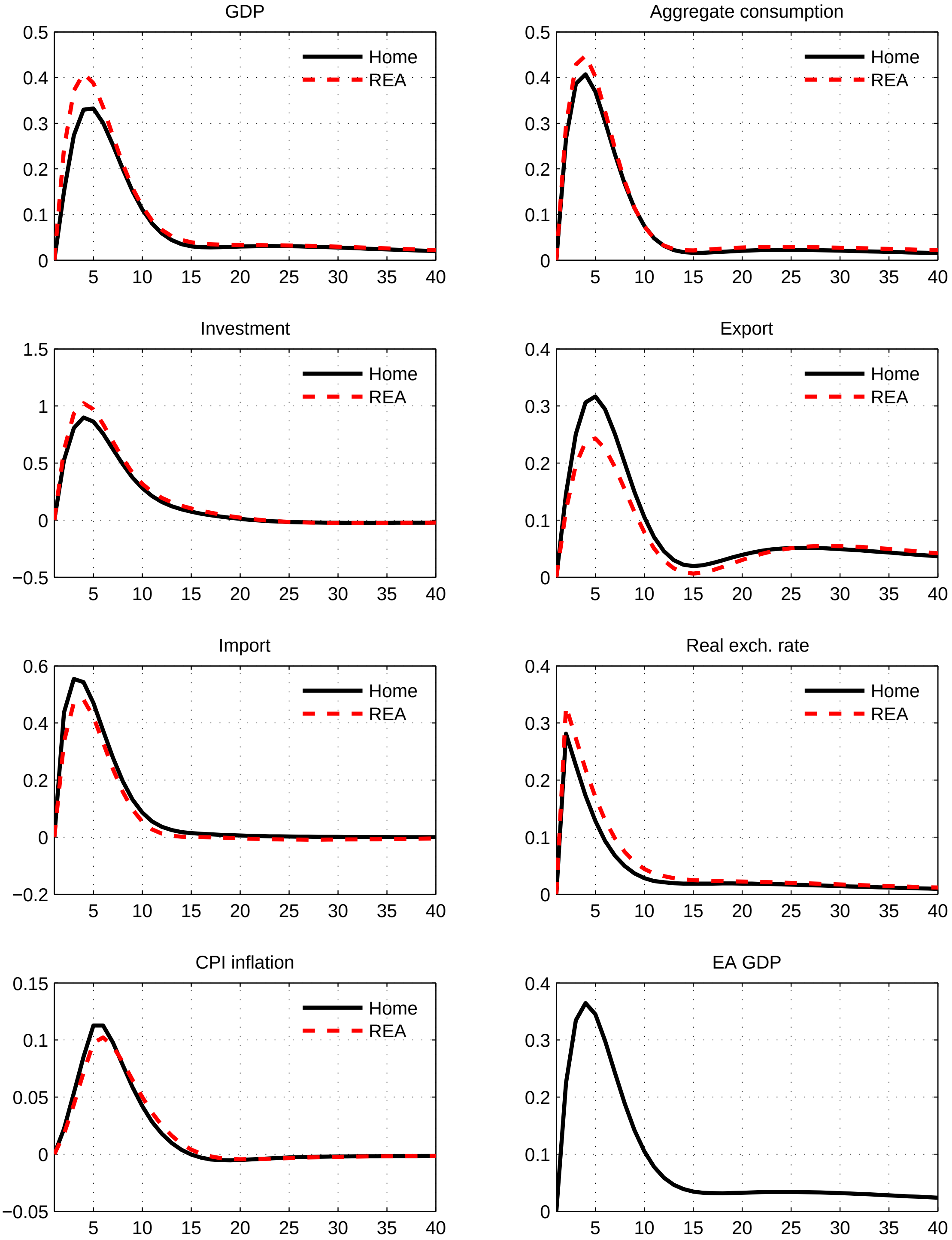
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for interest rates (annualized percentage-point deviations) and the interbank position-to-GDP ratio (percentage-point deviations).

Figure 1b. Reduction in the EA interest rate – Effects on borrowing and housing



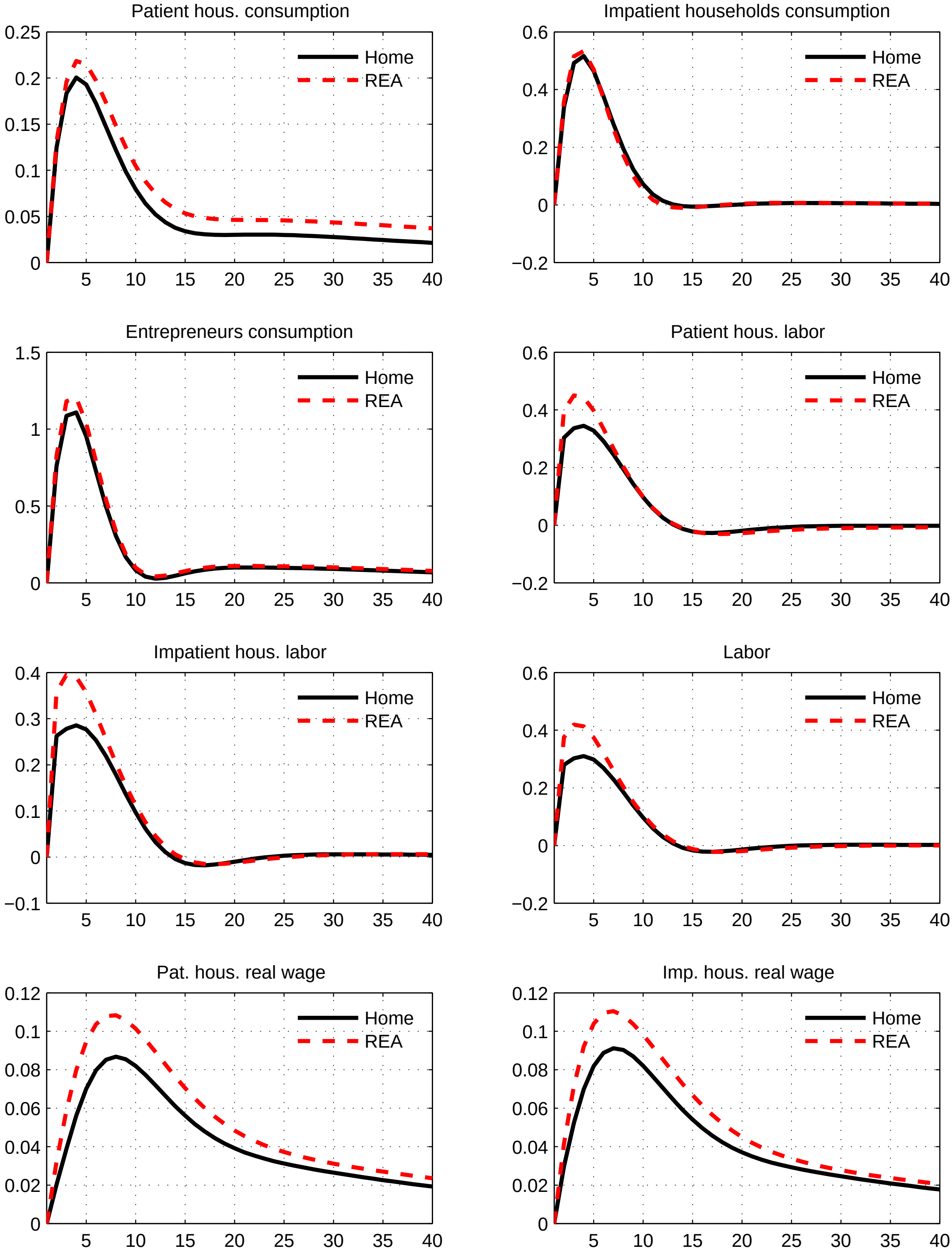
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 1c. Reduction in the EA interest rate – Effects on main macro variables



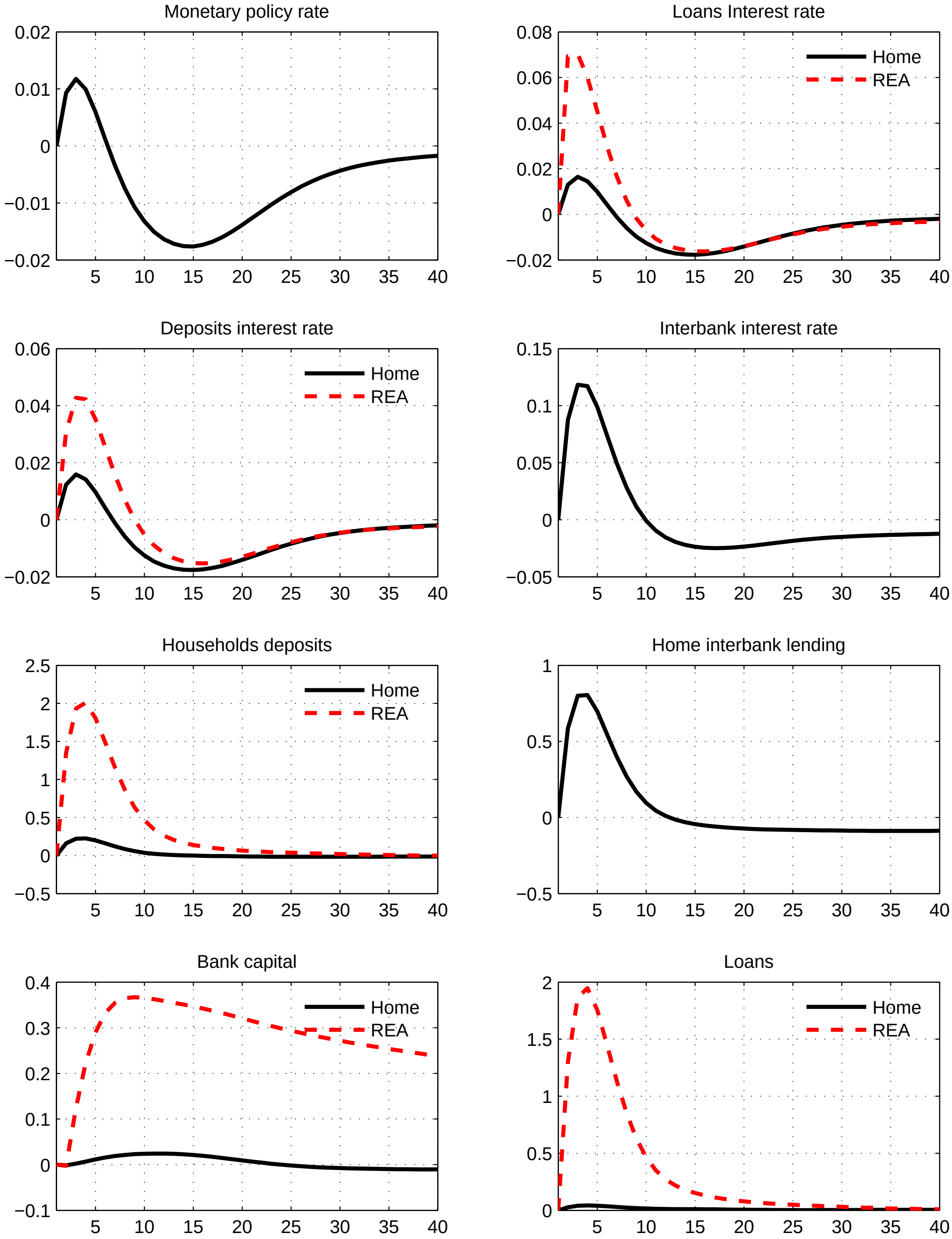
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for inflation (annualized percentage-point deviations). GDP and its components are reported in real terms.

Figure 1d. Reduction in the EA interest rate – Effects on consumption and labor



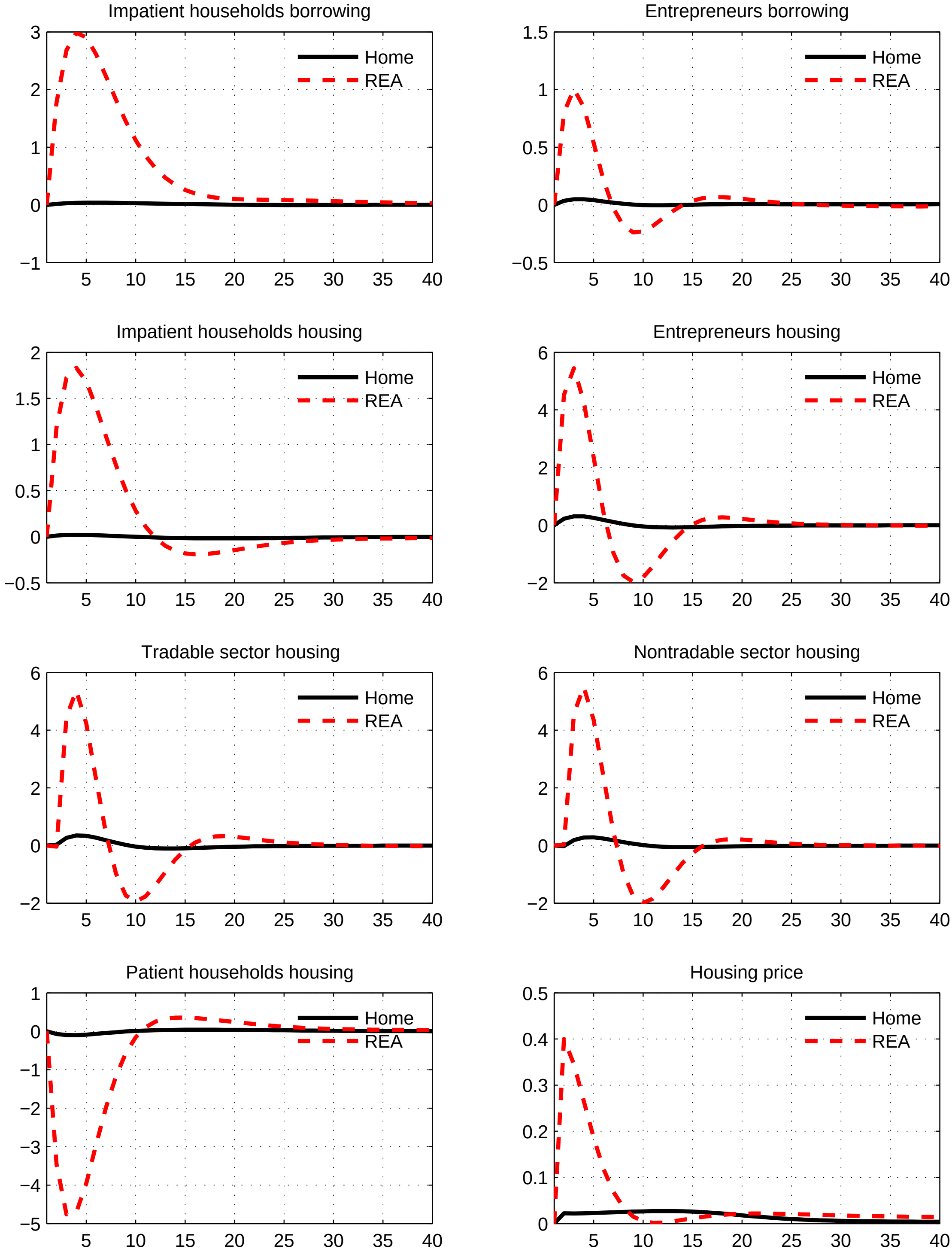
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 2a. Increase in REA LTV ratio – Effects on bank variables



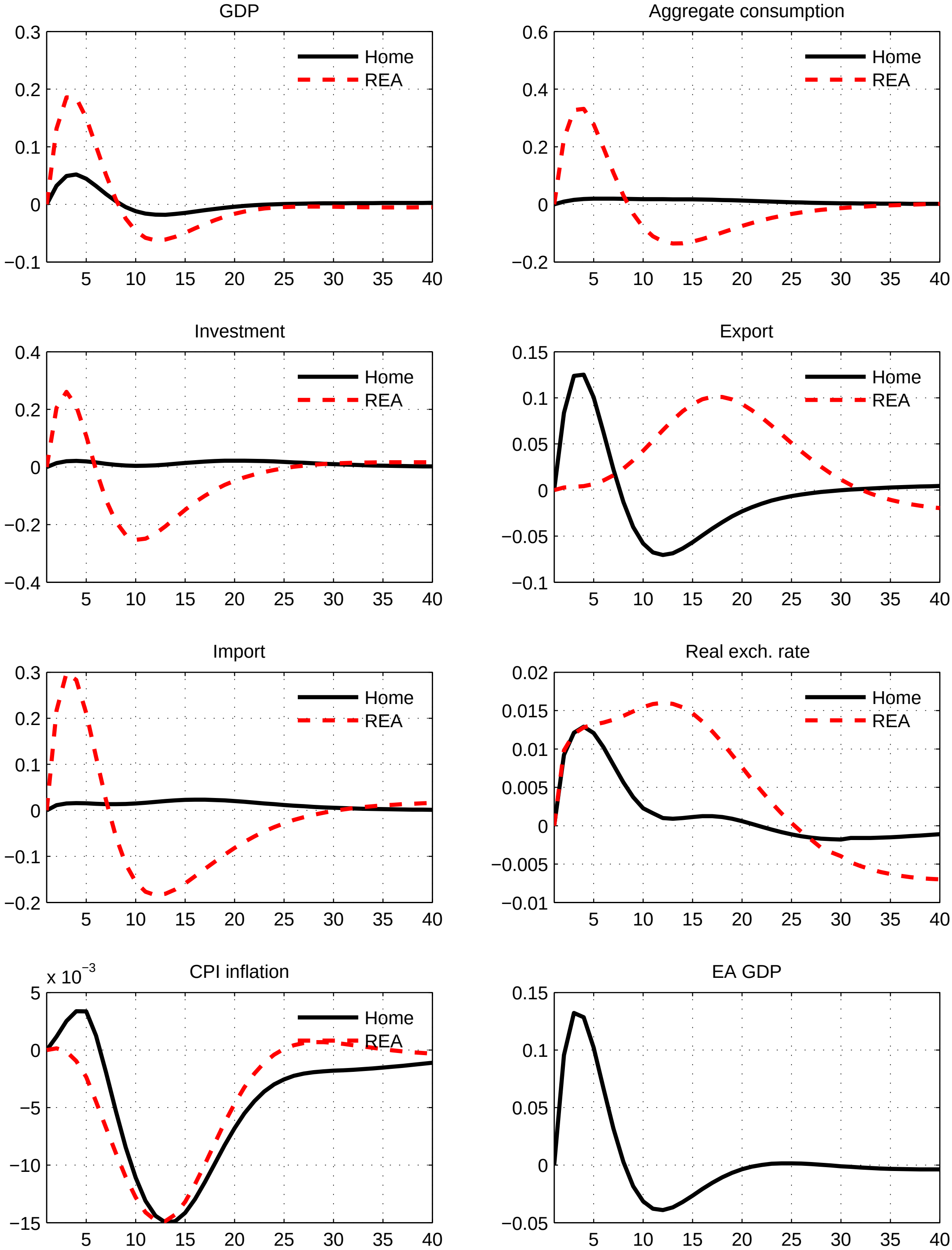
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for interest rates (annualized percentage-point deviations) and the interbank position-to-GDP ratio (percentage-point deviations).

Figure 2b. Increase in REA LTV ratio – Effects on borrowing and housing



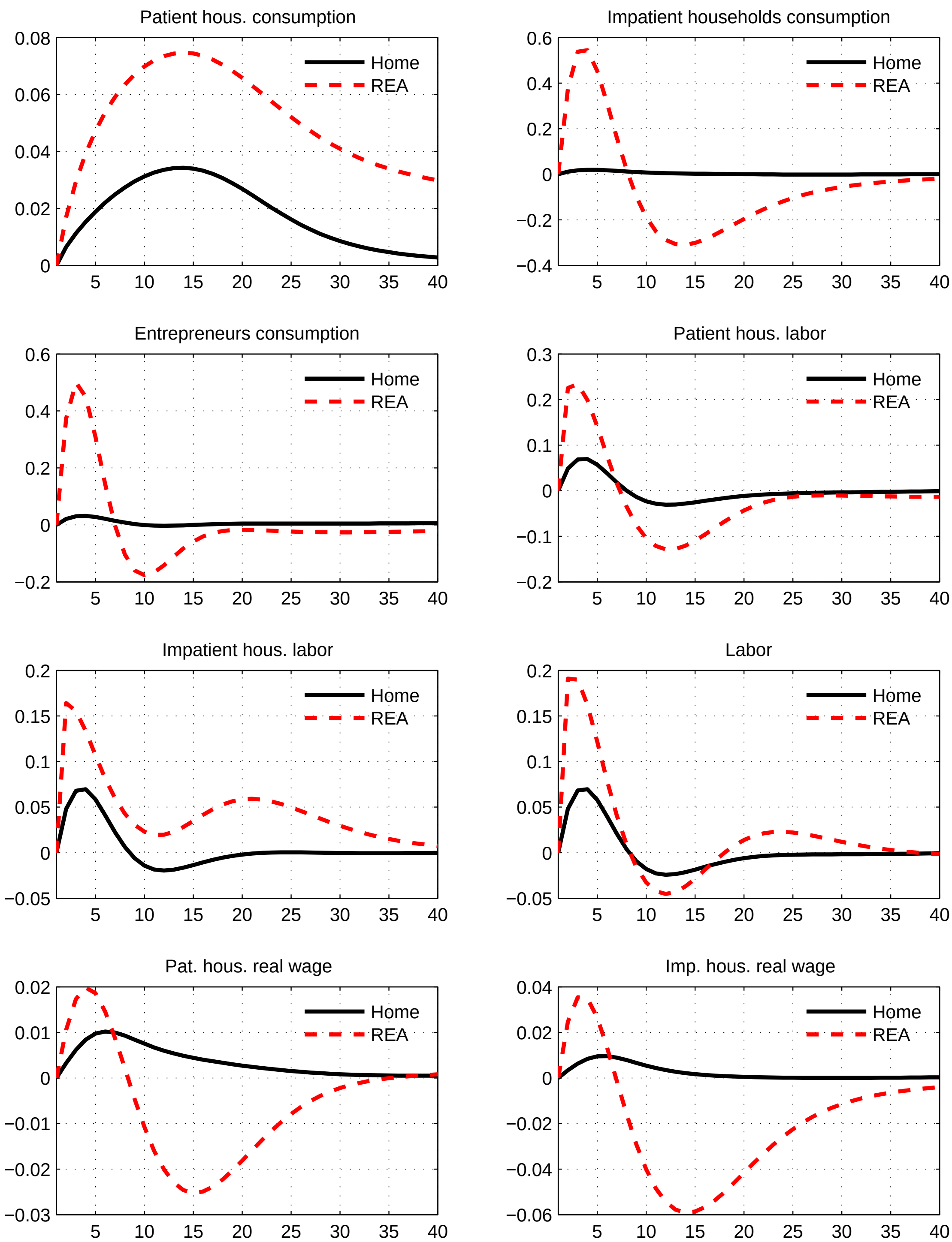
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 2c. Increase in REA LTV ratio – Effects on main macro variables



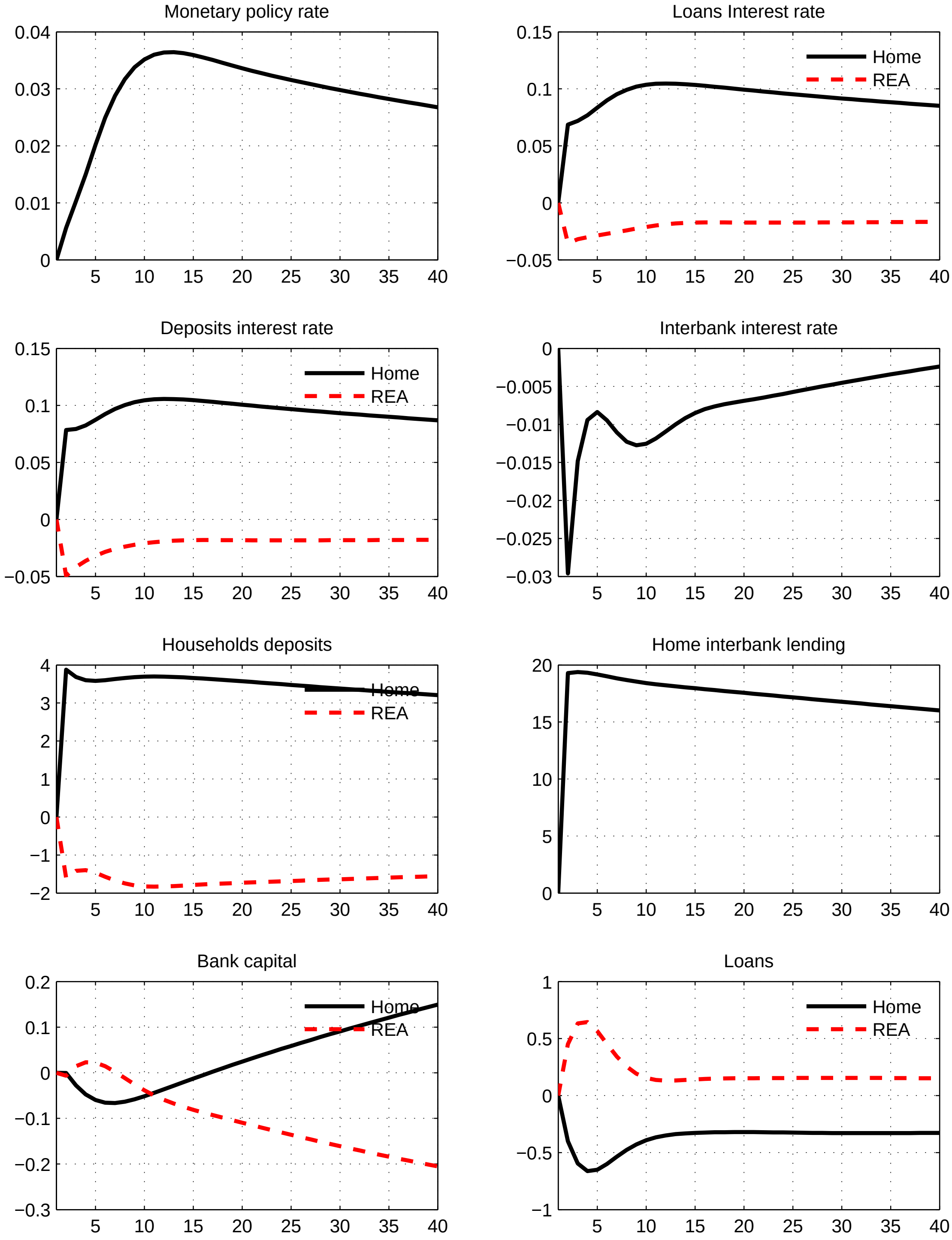
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for inflation (annualized percentage-point deviations). GDP and its components are reported in real terms.

Figure 2d. Increase in REA LTV ratio – Effects on consumption and labor



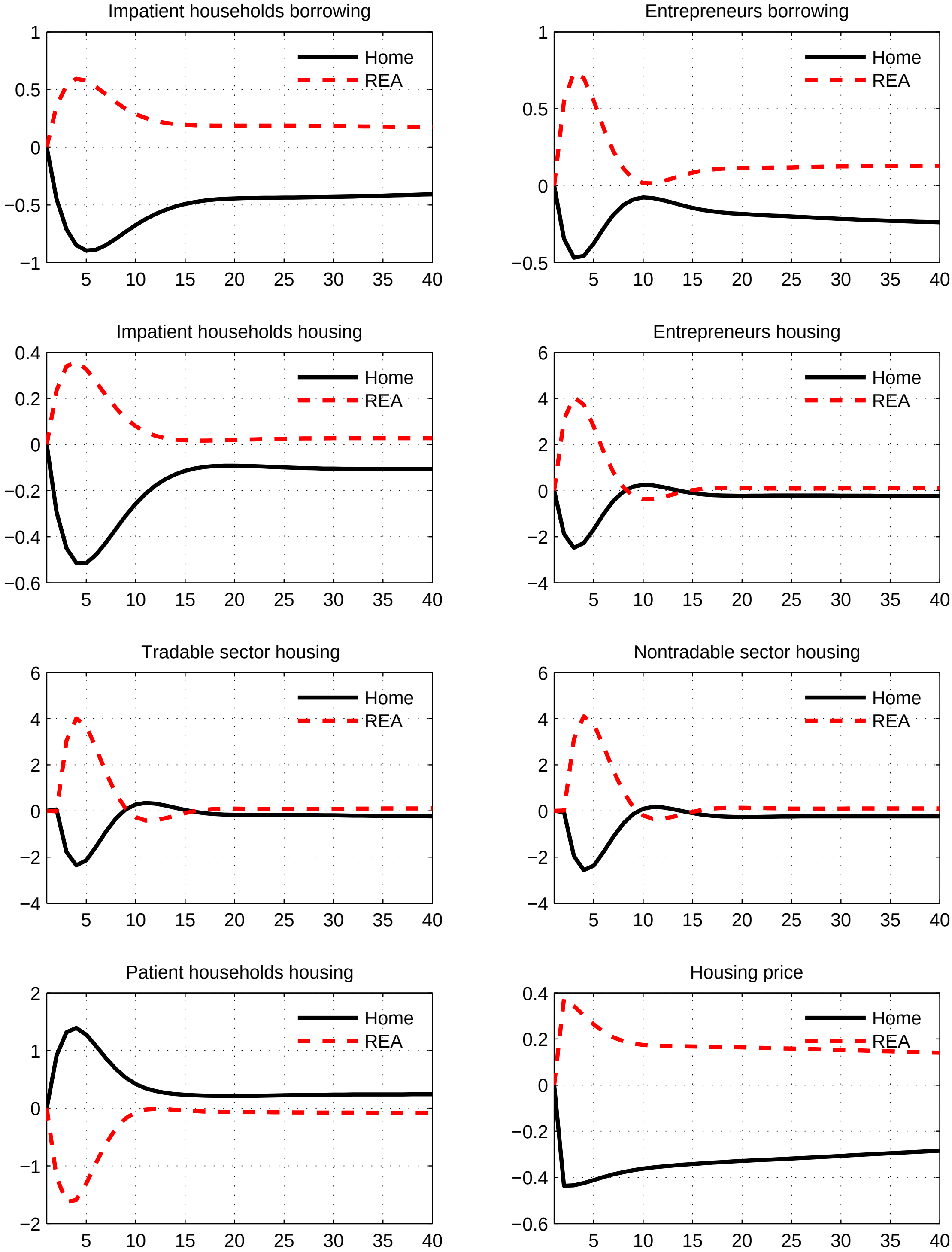
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 3a. Increase in Home long-run interbank position – Effects on bank variables



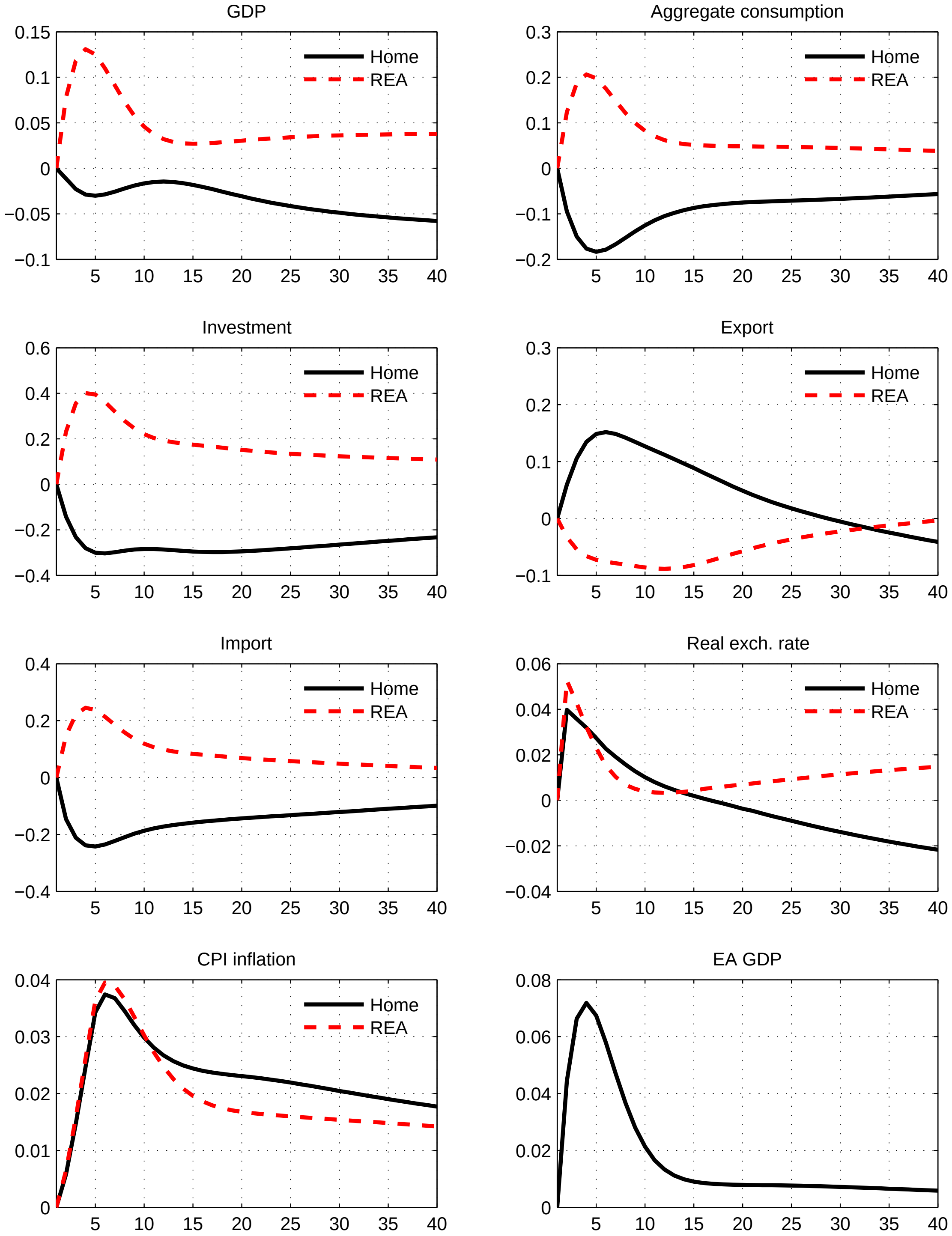
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for interest rates (annualized percentage-point deviations) and the interbank position-to-GDP ratio (percentage-point deviations).

Figure 3b. Increase in Home long-run interbank position – Effects on borrowing and housing



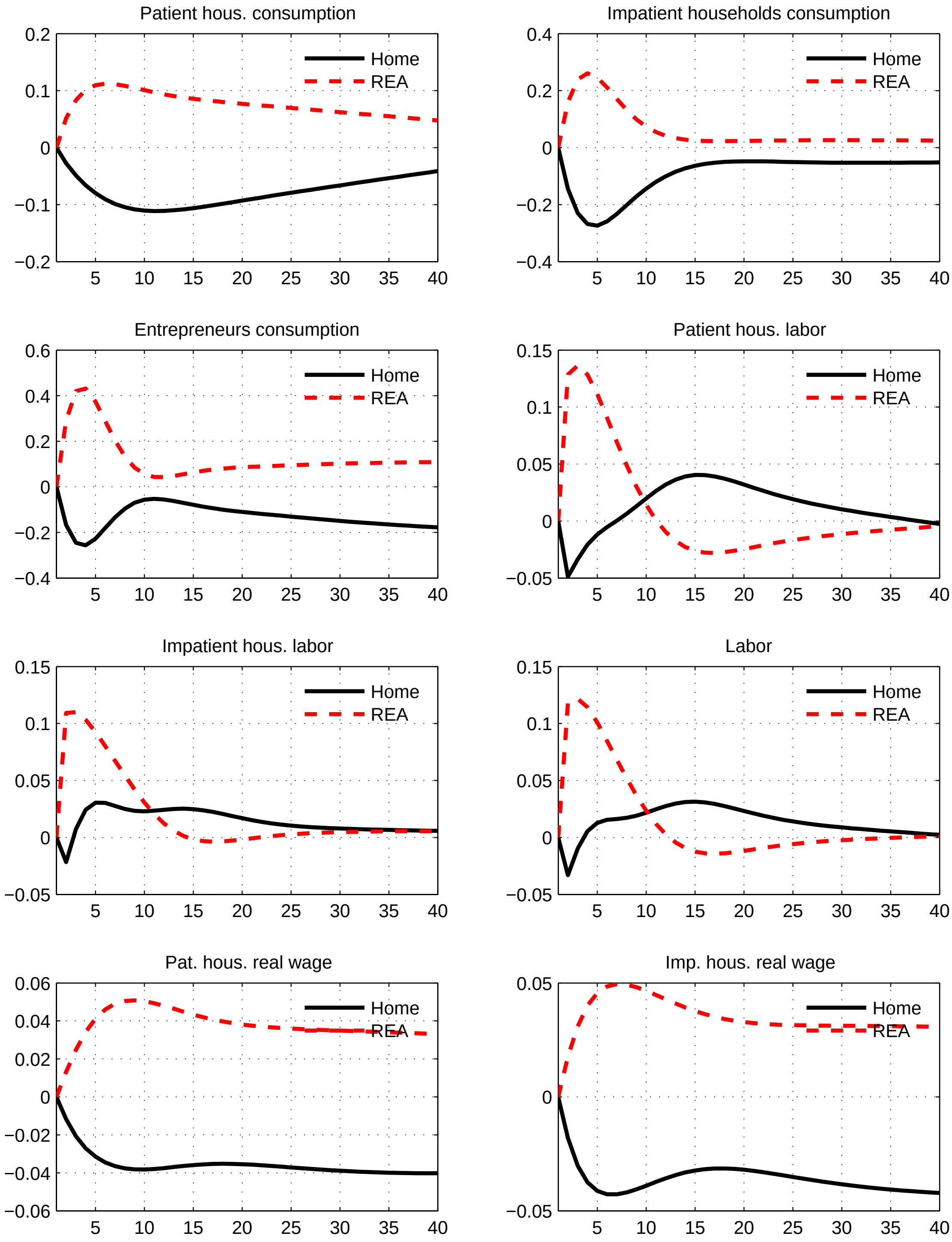
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 3c. Increase in Home long-run interbank position – Effects on main macro variables



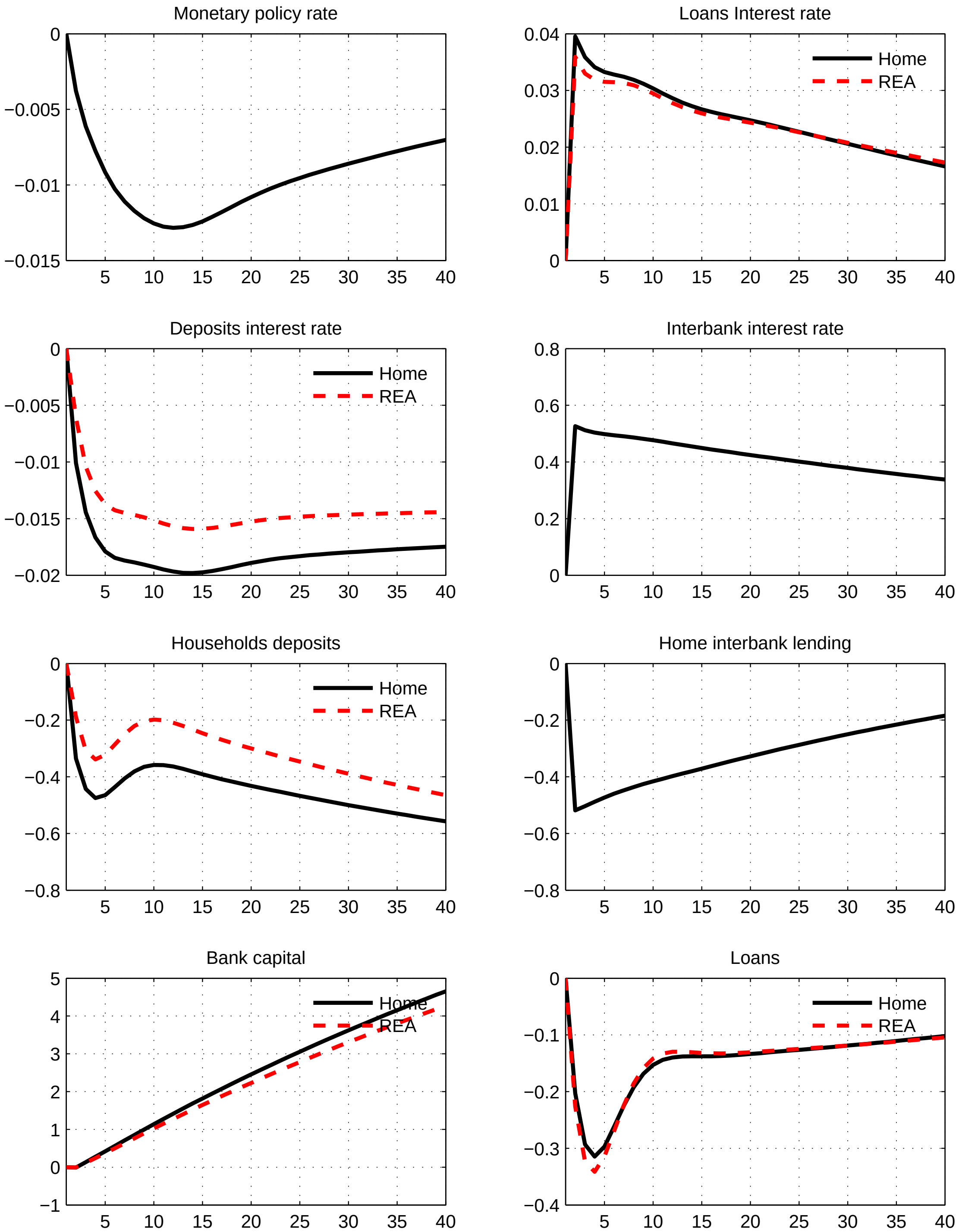
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for inflation (annualized percentage-point deviations). GDP and its components are reported in real terms.

Figure 3d. Increase in Home long-run interbank position – Effects on consumption and labor



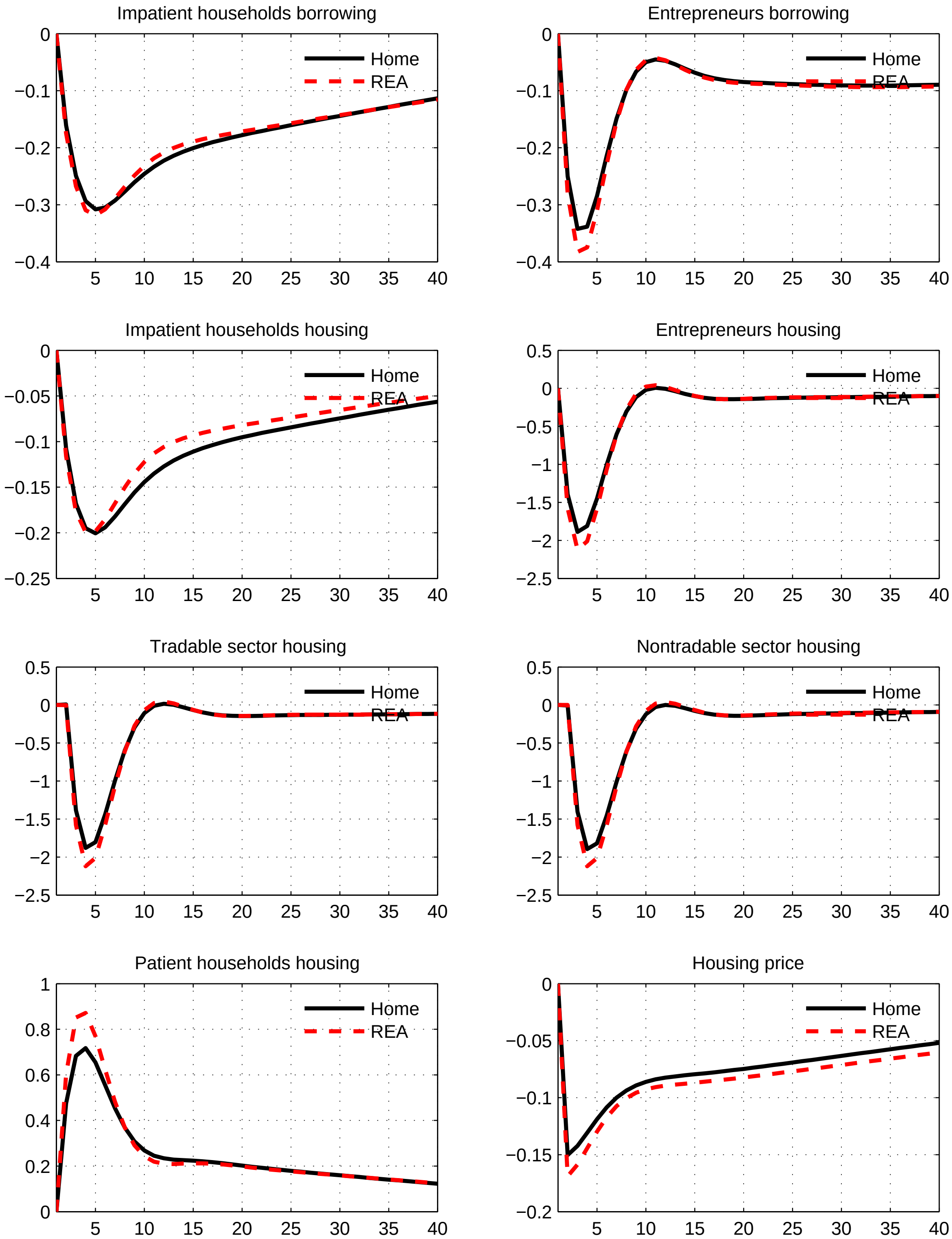
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 4a. Increase in EA bank capital requirement – Effects on bank variables



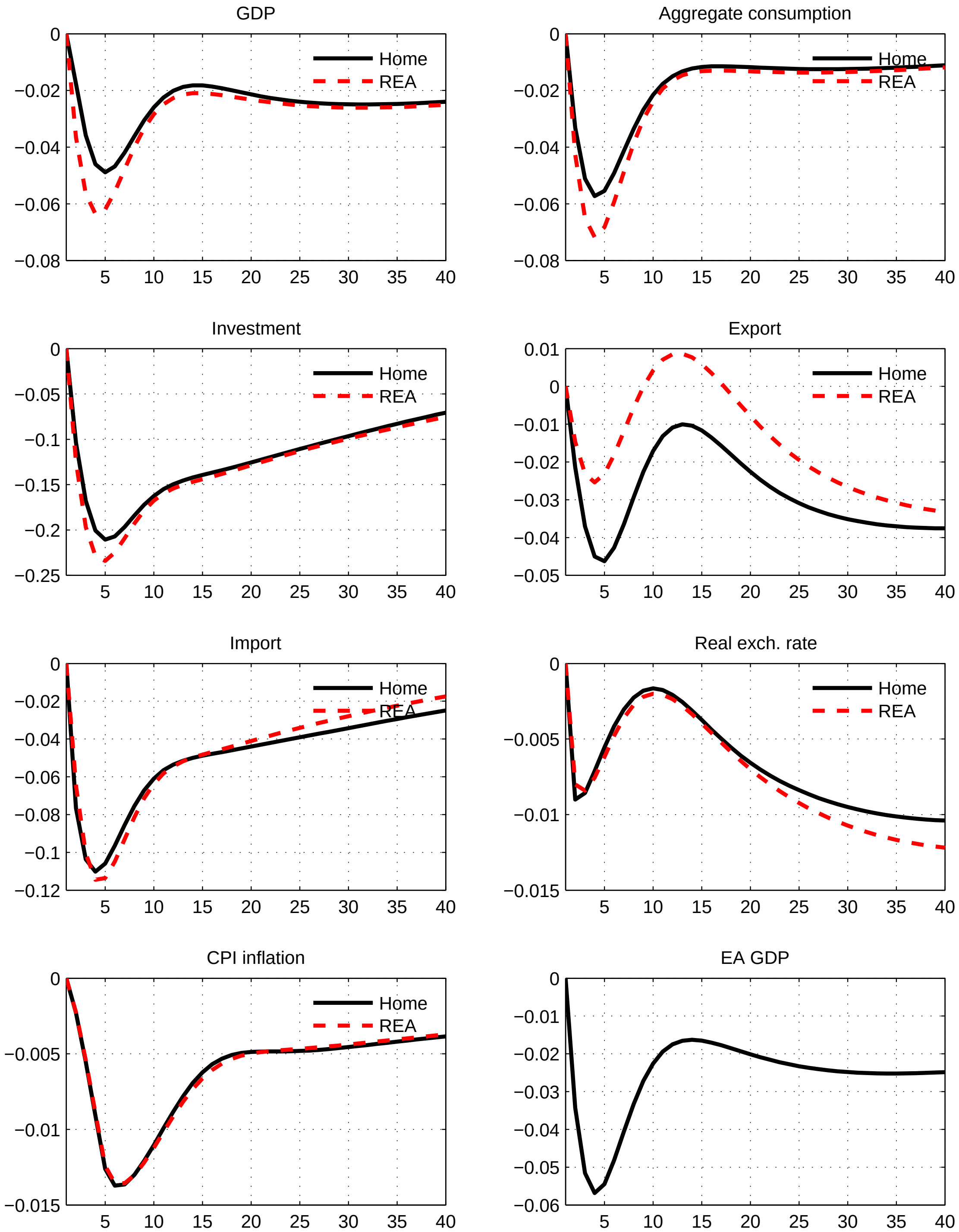
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for interest rates (annualized percentage-point deviations) and the interbank position-to-GDP ratio (percentage-point deviations).

Figure 4b. Increase in EA bank capital requirement – Effects on borrowing and housing



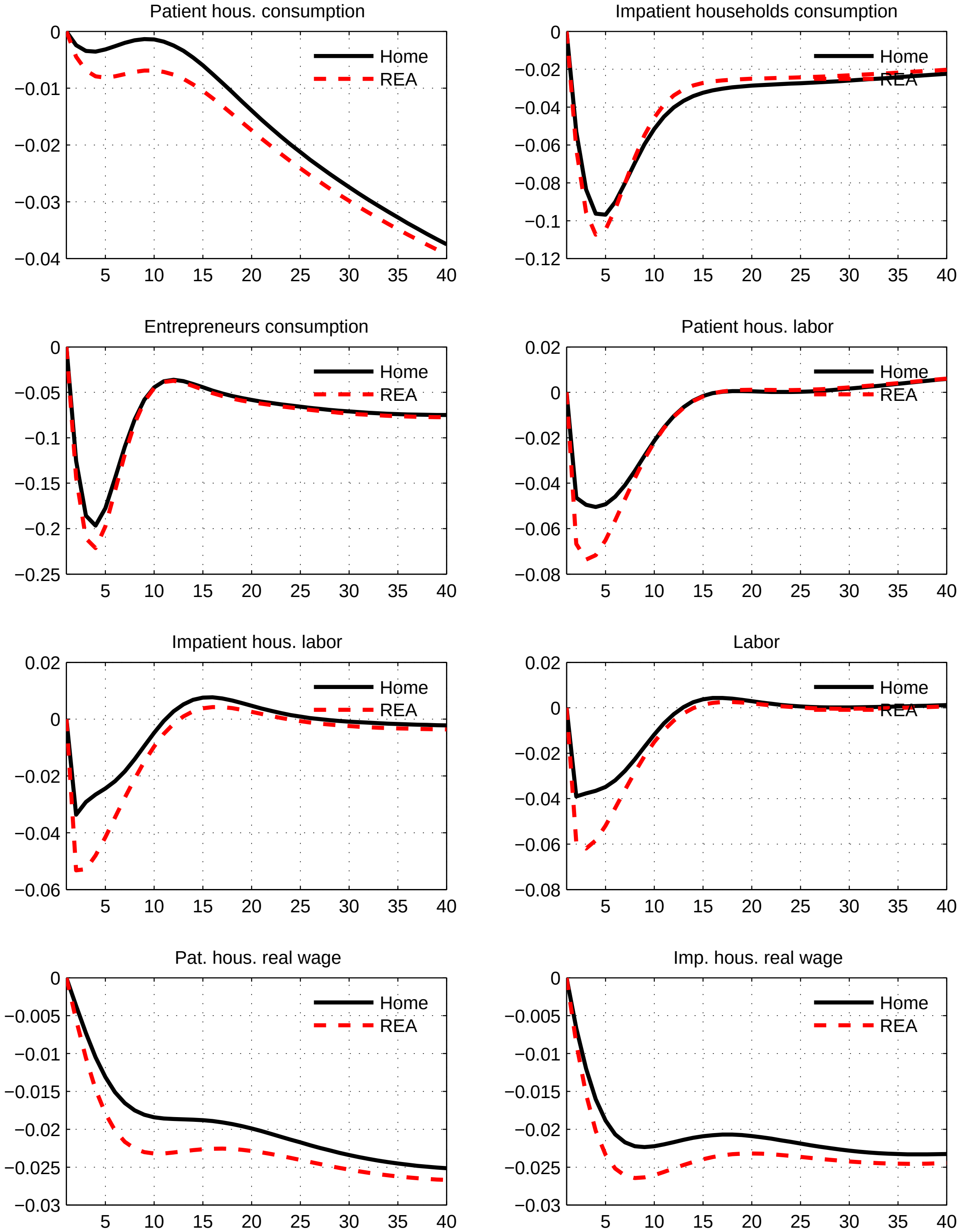
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 4c. Increase in EA bank capital requirement – Effects on main macro variables



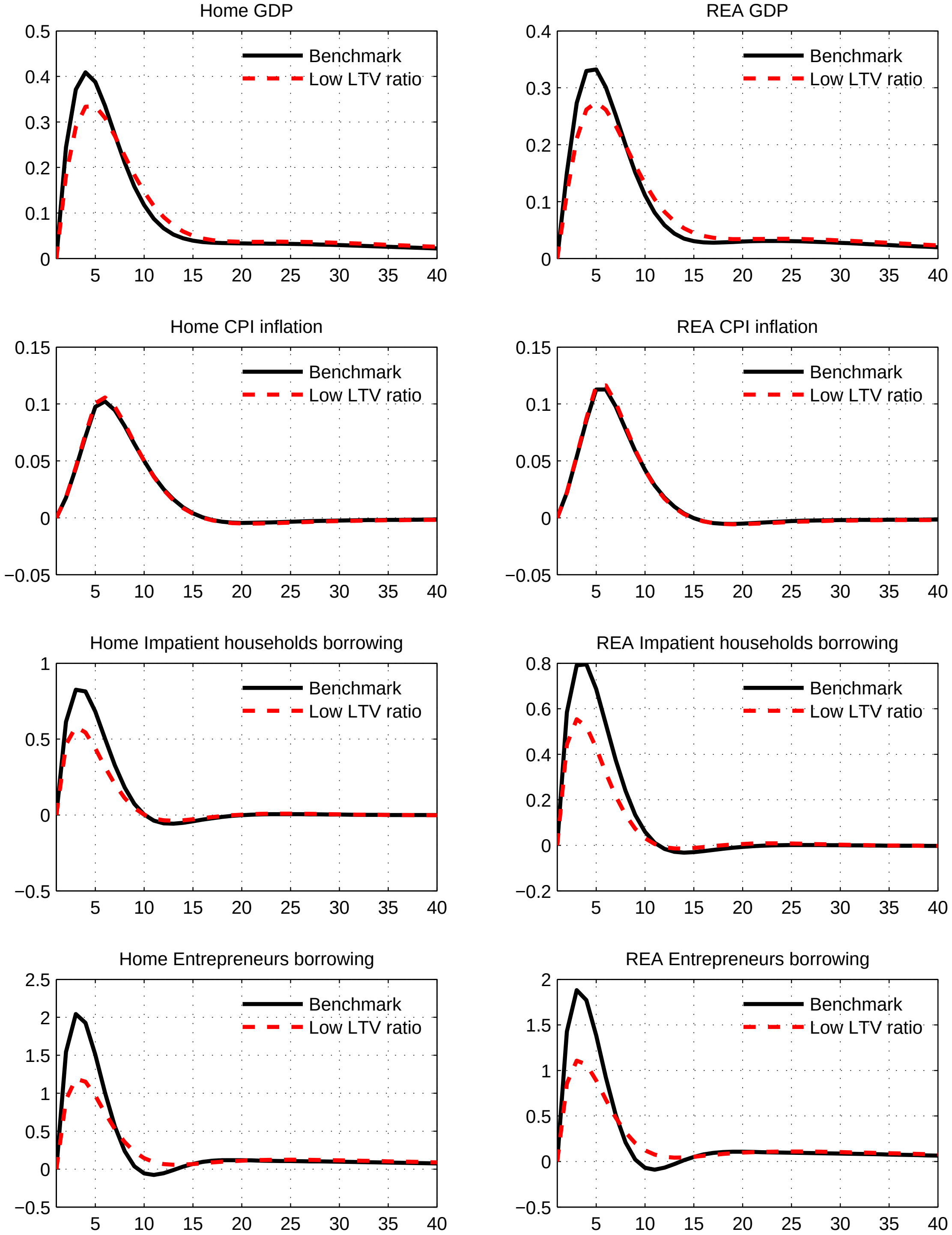
Horizontal axis: quarters. Vertical axis: % deviations from the baseline, except for inflation (annualized percentage-point deviations). GDP and its components are reported in real terms.

Figure 4d. Increase in EA bank capital requirement – Effects on consumption and labor



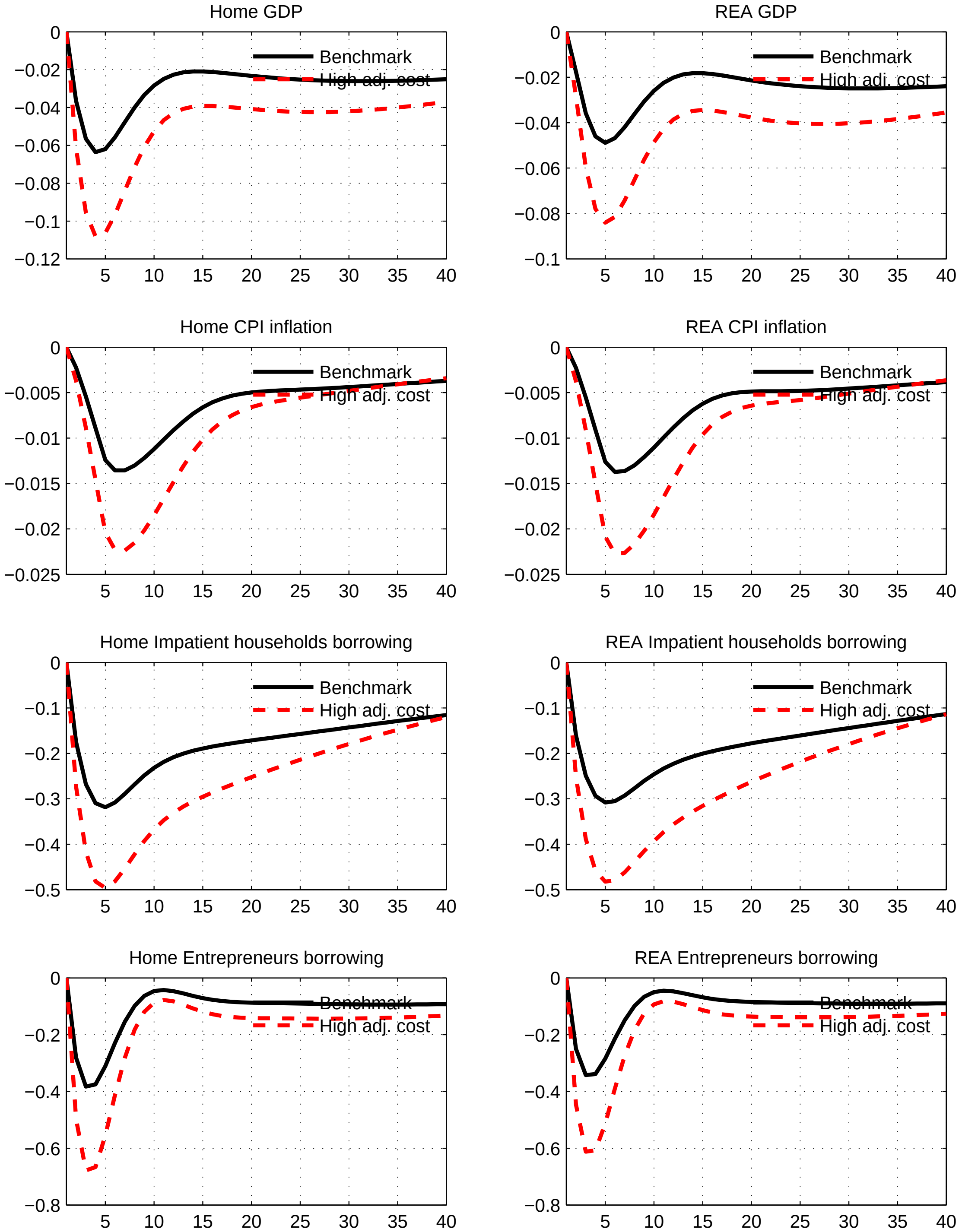
Horizontal axis: quarters. Vertical axis: % deviations from the baseline.

Figure 5. Sensitivity. Low LTV ratio



Horizontal axis: quarters. Vertical axis: % deviations from the baseline. Benchmark: LTV ratio=0.7; Low LTV ratio: LTV ratio=0.5.

Figure 6. Sensitivity. High adj. cost on bank capital γ_X



Horizontal axis: quarters. Vertical axis: % deviations from the baseline. Benchmark: adj.cost=0.001; High adj. cost: adj. cost=0.002.

Technical Appendix: Equations

Below we state the new equations (compared to the standard version of the EAGLE model), written in real terms. The price of consumption is the numeraire.

Banks first order conditions (FOC), budget constraint and capital requirement

- FOC Marginal utility of dividends

$$\Lambda_{B,t} = \left(div_t^B\right)^{-\sigma} \tag{62}$$

- FOC deposits supply

$$\Lambda_{B,t} = \beta_B E_t \left[\Lambda_{B,t+1} \frac{R_t^D}{\Pi_{C,t+1}}\right] - \Lambda_{B,t}\gamma_X \left(x_t - \bar{x}\right) \tag{63}$$

- FOC loans supply

$$\begin{aligned}\Lambda_{B,t} \quad = \quad & \beta_B E_t \left[\Lambda_{B,t+1} \frac{R_t^L}{\Pi_{C,t+1}}\right] - \gamma_L \Lambda_{B,t} \left(\frac{l_t}{l_{t-1}} - 1\right) \frac{1}{l_{t-1}} \\ & + \beta_B \gamma_L E_t \left[\Lambda_{B,t+1} \left(\frac{l_{t+1}}{l_t} - 1\right) \frac{l_{t+1}}{l_t^2}\right] \\ & - \Lambda_{B,t}\gamma_X (1 - \Upsilon_{K,t}) \left(x_t - \bar{x}\right)\end{aligned} \tag{64}$$

- FOC interbank loans

$$\Lambda_{B,t} = \beta_B E_t \left[\Lambda_{B,t+1} \frac{R_t^{IB}}{\Pi_{C,t+1}}\right] - \Lambda_{B,t}\gamma_{IB}(l_t^{IB} - \frac{\kappa^{IB}\overline{p}^Y\overline{Y}}{\omega_B}) - \Lambda_{B,t}\gamma_X \left(x_t - \bar{x}\right) \tag{65}$$

- budget constraint

$$\begin{aligned}div_t^B \quad = \quad & -l_t + \frac{R_{t-1}^L}{\Pi_{C,t}} l_{t-1} - l_t^{IB} + \frac{R_{t-1}^{IB}}{\Pi_{C,t}} l_{t-1}^{IB} \\ & + d_t^{Supply} - \frac{R_{t-1}^D}{\Pi_{C,t}} d_{t-1}^{Supply} - \Gamma_{L,t} - \Gamma_{IB,t} - \Gamma_{X,t}\end{aligned} \tag{66}$$

- capital requirement: excess bank capital definition

$$x_t \equiv (1 - \Upsilon_{K,t}) l_t - d_t^{Supply} + l_t^{IB} \tag{67}$$

- bank loans adjustment cost

$$\Gamma_L \equiv \frac{\gamma_L}{2} \left(\frac{l_t}{l_{t-1}} 1\right)^2 \tag{68}$$

- bank capital adjustment cost

$$\Gamma_X \equiv \frac{\gamma_X}{2} (x_t - \bar{x})^2 \tag{69}$$

- interbank loans adjustment cost

$$\Gamma_{IB} \equiv \frac{\gamma_{IB}}{2} \left(l_t^{IB} - \frac{\kappa^{IB} \overline{p}^Y \overline{Y}}{\omega_B} \right)^2 \tag{70}$$

Borrowers FOC, budget constraint and borrowing constraint

- FOC marginal utility of nondurables consumption

$$\Lambda_{J,t}(1+\tau_C) = \left(\frac{C_{J,t} - \kappa C_{J,t-1}}{1-\kappa} \right)^{-\sigma} \tag{71}$$

- FOC loans demand

$$\begin{aligned}
\Lambda_{J,t} &= \beta_J E_t \left[\Lambda_{J,t+1} \frac{R_t^L}{\Pi_{C,t+1}} \right] \\
&- \gamma_{B_J} \Lambda_{J,t} \left(\frac{b_{J,t}}{b_{J,t-1}} - 1 \right) \frac{1}{b_{J,t-1}} + \beta_J \gamma_{B_J} E_t \left[\Lambda_{J,t+1} \left(\frac{b_{J,t+1}}{b_{J,t}} - 1 \right) \frac{b_{J,t+1}}{b_{J,t}^2} \right] \\
&+ \Lambda_{JC,t} R_t^L - \rho_{b_J} \beta_J E_t \left[\Lambda_{JC,t+1} \frac{R_t^L}{\Pi_{C,t+1}} \overline{\Pi} \right]
\end{aligned} \tag{72}$$

- FOC real estate demand

$$\Lambda_{J,t} q_t^H = \frac{\iota_J}{H_{J,t}} + \beta_J E_t \left[\Lambda_{J,t+1} (1-\delta_H) q_{t+1}^H \right] + (1-\rho_{B_J}) \Lambda_{JC,t} V_{J,t} E_t \left[q_{t+1}^H \Pi_{C,t+1} \right] \tag{73}$$

- budget constraint

$$\begin{aligned}
b_{J,t} - \frac{R_{t-1}^L}{\Pi_{C,t}} b_{J,t-1} &= (1-\tau_N-\tau_{WH}) w_{J,t} N_{J,t} + \frac{tr_J}{\omega_J} \\
&- (1+\tau_C) C_{J,t} - q_t^H (H_{J,t} - (1-\delta_H) H_{J,t-1}) - \Gamma_{B_J,t}
\end{aligned} \tag{74}$$

- borrowing constraint

$$-b_{J,t} R_t^L \leq -\rho_{B_J} \overline{\Pi} b_{J,t-1} \frac{R_{t-1}^L}{\Pi_{C,t}} + (1-\rho_{B_J}) V_{J,t} E_t \left[q_{t+1}^H \Pi_{C,t+1} H_{J,t} \right] \tag{75}$$

- adjustment cost on borrowing position

$$\Gamma_{B_J,t} \equiv \frac{\gamma_{B_J}}{2} \left(\frac{b_{J,t}}{b_{J,t-1}} - 1 \right)^2 \tag{76}$$

Entrepreneurs FOC, budget constraint, borrowing constraint

- FOC marginal utility of nondurables consumption

$$\Lambda_{E,t}(1+\tau_{C,t}) = \left(\frac{C_{E,t} - \kappa C_{E,t-1}}{1-\kappa}\right)^{-\sigma} \tag{77}$$

- FOC real estate demand

$$\Lambda_{E,t} q_t^H = \beta_E E_t \left[\Lambda_{E,t+1} r_{H,t+1} + \Lambda_{E,t+1}(1-\delta_H) q_{t+1}^H\right] + (1-\rho_{B_E})\, \Lambda_{EC,t} V_{H_E,t} E_t \left[q_{t+1}^H \Pi_{C,t+1}\right] \tag{78}$$

- FOC loans demand

$$\begin{aligned}
\Lambda_{E,t} &= \beta_E E_t \left[\Lambda_{E,t+1} \frac{R_t^L}{\Pi_{C,t+1}}\right] \\
&- \gamma_L \Lambda_{E,t} \left(\frac{b_{E,t}}{b_{E,t-1}} - 1\right) \frac{1}{b_{E,t-1}} + \beta_E \gamma_{B_E} E_t \left[\Lambda_{E,t+1} \left(\frac{b_{E,t+1}}{b_{E,t}} - 1\right) \frac{b_{E,t+1}}{b_{E,t}^2}\right] \\
&+ \Lambda_{EC,t} R_t^L - \beta_E \rho_{B_E} \overline{\Pi} E_t \left[\Lambda_{EC,t+1} \frac{R_t^L}{\Pi_{C,t+1}}\right]
\end{aligned} \tag{79}$$

- FOC investment in physical capital

$$\begin{aligned}
p_t^I &= q_t^K \left(1 - \Gamma_{I,t} - \Gamma'_{I,t} I_{E,t}\right) \\
&\quad + \beta_E E_t \left[\frac{\Lambda_{E,t+1}}{\Lambda_{E,t}} q_{t+1}^K \Gamma'_{I,t+1} \frac{I_{E,t+1}^2}{I_{E,t}}\right]
\end{aligned} \tag{80}$$

- FOC physical capital

$$\begin{aligned}
\Lambda_{E,t} q_t^K &= \beta_E E_t \left[\Lambda_{E,t+1} (1-\tau_{K,t+1}) \left(r_{K,t+1} u_{t+1} - \Gamma_{u,t+1} p_{t+1}^I\right)\right] + \tau_{K,t} \delta_K p_t^I \\
&+ \beta_E E_t \left[\Lambda_{E,t+1} q_{t+1}^K (1-\delta_K)\right] + (1-\rho_{B_E})\, \Lambda_{EC,t} V_{K_E,t} E_t \left[q_{t+1}^K \Pi_{C,t+1}\right]
\end{aligned} \tag{81}$$

- FOC capacity utilisation

$$r_{K,t} = \Gamma'_{u,t} p_t^I \tag{82}$$

$$\Gamma'_u = \frac{(\beta_E^{-1} - 1 + \delta_K)\overline{q}_K - \delta_K \overline{\tau}_K \overline{p}^I}{(1-\overline{\tau}_K)\overline{p}^I} + \gamma_{u2}(u_t - 1) \tag{83}$$

- Physical capital accumulation

$$K_{E,t} = (1-\delta_K) K_{E,t-1} + (1-\Gamma_{I,t}) I_{E,t} \tag{84}$$

- budget constraint

$$\begin{aligned} b_{E,t}-\frac{R^L_{t-1}}{\Pi_{C,t}}b_{E,t-1} &= r_{H,t}H_{E,t-1}+(1-\tau_{K,t})\left(r_{K,t}u_t-\Gamma_{u,t}p^I_t\right)K_{E,t-1}+\tau_{K,t}\delta_K p^I_t K_{E,t-1} \\ &- q^H_t\left(H_{E,t}-(1-\delta_H)H_{E,t-1}\right)-(1+\tau_{C,t})\,C_{E,t}-p^I_t i_{E,t} \\ &- \Gamma_{B_E,t} \end{aligned} \tag{85}$$

- borrowing constraint

$$-R^L_t b_{E,t}\leq -\rho_{B_E}\overline{\Pi}b_{E,t-1}\frac{R^L_{t-1}}{\Pi_{C,t}}+(1-\rho_{B_E})\,V_{H_E,t}E_t\left[q^H_{t+1}H_{E,t}\Pi_{C,t+1}\right]+(1-\rho_{B_E})\,V_{K,t}E_t\left[q^K_{t+1}K_{E,t}\Pi_{C,t+1}\right] \tag{86}$$

- adjustment cost on borrowing position

$$\Gamma_{B_E,t}\equiv\frac{\gamma_{B_E}}{2}\left(\frac{b_{E,t}}{b_{E,t-1}}-1\right)^2 \tag{87}$$

Savers' FOC

- FOC marginal utility of nondurables consumption

$$\Lambda_{I,t}(1+\tau_C)=\left(\frac{C_{I,t}-\kappa C_{I,t-1}}{1-\kappa}\right)^{-\sigma} \tag{88}$$

- FOC deposits demand

$$\Lambda_{I,t}\left[1+\gamma_{DH}\left(d^{Dem}_t-\frac{\kappa^D\overline{p}^Y\overline{Y}}{1-\omega_J-\omega_E-\omega_B}\right)\right]=\beta_I E_t\left[\Lambda_{I,t+1}\frac{R^D_t}{\Pi_{C,t+1}}\right] \tag{89}$$

- FOC real estate demand

$$\Lambda_{I,t}q^H_t=\frac{\iota_I}{H_{I,t}}+\beta_I E_t\left[\Lambda_{I,t+1}(1-\delta_H)q^H_{t+1}\right] \tag{90}$$

Intermediate goods production

- Production functions

$$Y^{S,N}_t = z_{N,t}\left(K^D_t\right)^{\alpha_{KN}}\left(H^D_t\right)^{\alpha_{HN}}\left(N^D_t\right)^{1-\alpha_{KN}-\alpha_{HN}} \tag{91}$$

$$Y^{S,T}_t = z_{T,t}\left(K^D_t\right)^{\alpha_{KT}}\left(H^D_t\right)^{\alpha_{HT}}\left(N^D_t\right)^{1-\alpha_{KT}-\alpha_{HT}} \tag{92}$$

- Input demand functions

$$r_{H,t}H_t^{N,D} = \alpha_{HN}Y_t^{S,N}MC_t^N \tag{93}$$
$$r_{H,t}H_t^{T,D} = \alpha_{HT}Y_t^{S,T}MC_t^T \tag{94}$$
$$r_{K,t}K_t^{N,D} = \alpha_{KN}Y_t^{S,N}MC_t^N \tag{95}$$
$$r_{K,t}K_t^{T,D} = \alpha_{KT}Y_t^{S,T}MC_t^T \tag{96}$$

Market clearing conditions and net foreign asset position

- Housing market

$$(1-\omega_J-\omega_E-\omega_B)H_{I,t}+\omega_J H_{J,t}+\omega_E H_{E,t}=\bar{H}; \tag{97}$$

$$H_t^T + H_t^{NT} = \omega_E H_{E,t} \tag{98}$$

- Loans market

$$\omega_B l_t + \omega_J b_{J,t} + \omega_E b_{E,t} = 0 \tag{99}$$

- Deposits market

$$\omega_B d_t^{Supply} = (1-\omega_J-\omega_E-\omega_B)d_t^{Dem} \tag{100}$$

- EA cross-country interbank market ($L_t^{IB,REA}$ is in H "real" currency)

$$s^H\omega_B^H l_t^{IB,H} + s^{REA}\omega_B^{REA} l_t^{IB,REA} = 0 \tag{101}$$

- Net foreign assets position (in "real" US dollars)

$$\begin{aligned}(1-\omega_J-\omega_E-\omega_B)B_{US,t}+\omega_B\frac{L_t^{IB}}{S_t^{H,US}}+(1-\omega_J-\omega_E-\omega_B)\frac{B_{I,t}^{EA}}{S_t^{H,US}} =\\ (1-\omega_J-\omega_E-\omega_B)B_{US,t-1}R_{t-1}^{US}+\omega_B\frac{L_{t-1}^{IB}R_{t-1}^{IB}}{S_t^{H,US}}\\ +(1-\omega_J-\omega_E-\omega_B)\frac{B_{I,t-1}^{EA}R_{t-1}}{S_t^{H,US}}+\frac{TB_t^H}{S_t^{H,US}},\end{aligned} \tag{102}$$

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