Monetary policy in an Open Economy: The Role of Financial Dollarization

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Abstract

This paper extends the Gerali et al. (2010) model to an open economy model with dual-currency banking and endogenously determined dollarization. The model incorporates a portfolio allocation problem in households' and entrepreneurs' decisions, so that they choose optimal currency structure of their deposits and loans based on interest rate differentials and their expectations about exchange rate movements. The optimal structure of deposit and loan portfolios yields in disparate dollarization rates.

The model is estimated for Armenia using the data from 2004 to 2014. The comparison of the models with and without dollarization reveals significant differences in macroeconomic effects of monetary policy in dollarized economies, since it primarily affects the economic activity by exchange rate channel, rather than by interest rate channel. This result claims for a different approach to monetary policy implementation in dollarized countries.

Keywords: DSGE, monetary policy, financial dollarization, Armenia.
JEL Classification Codes: E44, E47, E52, E58.

1 Introduction

DSGE models are extensively used in many central banks for policy analysis and forecasting. However those models are mainly oriented to explaining the nominal rigidities in prices and wages, as well as, real rigidities, whereas financial intermediaries often are missing or are included only implicitly. The Financial crisis of 2008/09 showed that those standard New-Keynesian models are not able to fully capture the modern business cycle fluctuations and that other sectors of economy, namely financial markets and institutions, should be taken seriously in DSGE modeling. Thereby the crisis caught the interest of researchers towards developing new models with financial frictions.

The new stream of DSGE models incorporating financial accelerator and credit constraints based on seminal works of Bernanke et al. (1999) and Iacoviello (2005) aimed to assess the macroeconomic effects of financial frictions in closed economies (see Christiano et al. (2010); Gerali et al. (2010)). Open economy versions of financial accelerator framework were developed by Christiano et al. (2011) and others. Several extensions of Gerali et al. (2010) incorporated interbank markets (see. Hilberg and Hollmayr (2011)). However, to my knowledge, there is no open economy model in the literature with micro-founded banking system and financial dollarization, which could be applicable for a wide range of emerging market countries with financial market imperfections. This paper attempts to fill this gap in literature developing an open economy DSGE model with financial dollarization and fully micro-founded banking system.

In the paper the role of dynamically changing financial dollarization on monetary policy implementation is studied. For this purpose the Gerali et al. (2010) model has been extended to an open economy framework with dual-currency banking and endogenously determined financial dollarization. We introduce portfolio allocation problem in households' and entrepreneurs' decisions, so that they choose optimal currency structure of their deposits and loans based on interest rate differentials and their expectations about exchange rate movements. The optimal structure of deposit and loan portfolios yields in disparate dollarization rates.

Banks play a key role in the model by bearing the risks of changing dollarization. The optimal structure of deposit and loan portfolios implies disparate dollarization rates that gives rise to an excess demand or supply of foreign currency at the household level which is then transmitted to the banking sector. With deposit and loan dollarization rates changing independently in both sides of their balance sheets, banks have to maintain closed FX positions by borrowing or lending in foreign interbank market. This feature provides an additional source of macroeconomic volatility due to dynamically changing dollarization via balance of payments and exchange rate fluctuations.

The analysis shows that even small amount of dollarization has significant effects on the dynamics of the economy. Moreover the macroeconomic effects of monetary policy with presence of dollarization are very different from those with no dollarization. This results claims for a different approach to monetary policy implementation in dollarized countries.

The remainder of the thesis is structured as follows. The Section 2 discusses some relevant papers with similar methods and approaches employed here, in Section 3 the model economy and the behavior of the agents in the model is introduced, Section 4 presents the results of Bayesian estimation for Armenian economy and Section 5 analyzes the properties of the model. The Appendices present the detailed derivation of model equations, the steady state of the model and some results from estimation.

2 Literature review

The literature on DSGE models with financial frictions has been expanding in two directions: external financing premium and credit constraints. The former approach tries to incorporate financial market imperfections, such as asymmetric information between lenders and borrowers, into a standard New Keynesian Models, whereas the latter is intended to assess the role of collateral effects in business cycle fluctuations.

Bernanke et al. (1999) build a model with credit relations between the households and the entrepreneurs. They used the framework to study the effects of a monetary policy shock and to compare it to the standard new Keynesian framework without financial intermediaries. They find that an interest rate shock generates a feedback loop between capital demand, entrepreneurs' net worth and external financing premium, which amplifies he effect of the shock. The authors conclude that the role of the financial accelerator is highly pro-cyclical as it worsens the outcome of a contractionary monetary policy.

The pioneering work of Bernanke et al. (1999) gave raise to a new stream of DSGE models trying to explain the role of financial factors in business cycle fluctuations. Christiano et al. (2010) extended the financial accelerator framework to include financial frictions and unemployment. The authors concluded that generally the introduction of the banking funding channel was supported by the data. The financial shocks in the model seemed to play an important role as a source of business cycle fluctuations. Moreover, they find evidence that it is desirable for the monetary policy to target not only inflation and output gap, but also the variables related to the stock market to stabilize economic activity.

Iacoviello (2005) developed a model incorporating borrowing constraints for households and entrepreneurs. He also introduced nominal contracts instead of real ones used in earlier models. This assumption appeared to be more realistic, as it allowed to evaluate the role of inflation in the credit cycle. He found that the introduction of nominal contracts stabilized supply shocks, but amplified demand shocks. At the same time collateral constraints increased the responsiveness of aggregate demand to housing prices.

Gerali et al. (2010) developed and estimated a DSGE model for the Euro Area that incorporated a monopolistically competitive banking sector with considerable market power in retail markets. The model had two types of consumers (lending and borrowing) holding CES baskets of financial services which enables monopolistic competition between bank branches. In addition to imperfect competition, they assume that banks face quadratic costs when they change deposit or loan interest rates thereby introducing short-run rigidities in financial markets and weaker performance of the interest rate channel of monetary policy. The authors fount that financial shocks were the main sources of downturn in Euro Area during the crisis of 2008/09.

Brzoza-Brzezina and Makarski (2011) extended Gerali et al. (2010) model to an open economy framework with bank borrowing/lending in home currency. They used the model to analyze the effects of credit contraction and its role in the downturn of 2008/09 in Poland. According to their estimates, the contribution of the shocks from financial sector in the slowdown accounted for about 1.5 percent of GDP.

Empirical work on the effects of financial dollarization on business cycle dynamics shows that generally partial dollarization has countercyclical effects. With prices and interest rates mainly determined by foreign factors, those economies appear to have smoother dynamics and stabilized domestic shocks, but weak interest rate channel of monetary policy. On the other hand, those countries are more vulnerable to foreign shocks , in the same time having more effective exchange rate channel.

The role of dollarization in macroeconomic models is being studied mainly in the form of transactions dollarization. The effects of currency substitution and price dollarization in emerging economies were studied by Castillo et al. (2013). The authors developed and estimated a small open economy model for Peru using Bayesian methods. They found, that both types of dollarization were supported by the Peruvian data. According to them the presence of dollarization had countercyclical effects, dampening the monetary policy shock by two times, thereby reducing the effectiveness of the interest rate channel.

Another two country model developed by Yang et al. (2008) incorporated Money-in-Utility households and partial transactions/liability dollarization. They embedded financial accelerator mechanism with corporate borrowing in foreign currency. Financial frictions combined with liability dollarization appeared to magnify the effects of productivity and country risk premium shocks on private investment.

A general equilibrium model based on portfolio decisions of consumers was developed by Ize and Yeyati (2003) trying to assess the determinants of deposit and loan dollarization. In the model dollarization emerged as an optimal allocation of deposits and loans into home and foreign currencies derived from the optimizing behavior of risk averse agents. The authors showed that in a minimum variance portfolio the share of foreign currency is a function of inflation and real exchange rate volatilities whereas deviations from the optimal allocation can arise due to interest rate differentials.

The literature on financial dollarization with an explicit banking sector in very scarce. One of the few papers in this field is Brzoza-Brzezina et al. (2015) which incorporates foreign currency lending in a small open economy model to analyze its implications for monetary and macro-prudential policies. The authors find that foreign currency lending reduces the effectiveness of monetary policy, but has little effect on macro-prudential policy implementation. According to their results this feature is welfare increasing in a volatile domestic interest rate environment, while being welfare decreasing in case of external shocks.

3 The Model

3.1 Model environment

The core framework for the model is the closed economy model of Gerali et al. (2010) estimated for The Euro Area. Weextend their model to an open economy framework with dual-currency banking and endogenously determined financial dollarization.

The main blocks of the model are: Household sector (patient consumers, impatient consumers, entrepreneurs, financial intermediaries), Goods producing sector(capital producers, retail firms, final goods producers and importers), Banking sector (commercial banks and the central bank).

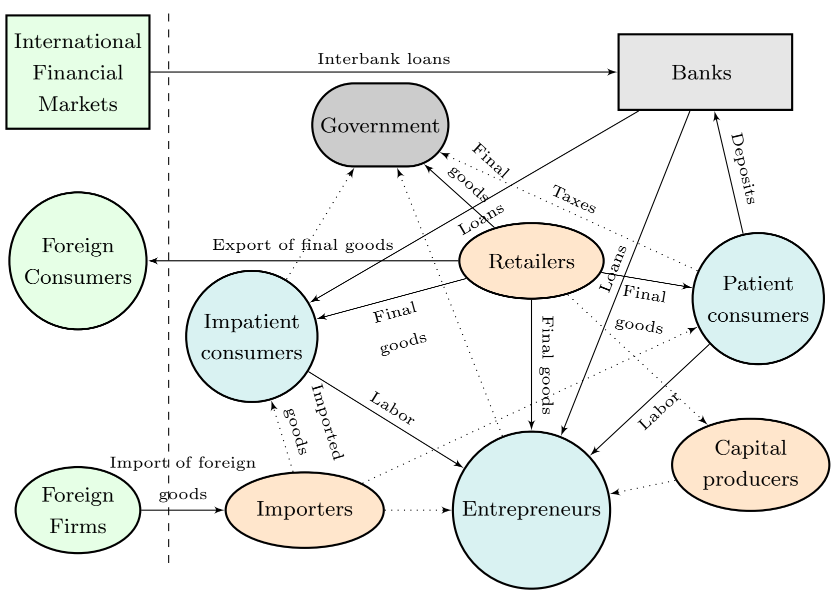

Figure 1: The model economy

3.2 Households and Entrepreneurs

There are two types of consumers in the model: patient and impatient. Patient consumers are net savers, whereas impatient consumers are net borrowers. They also differ from each other in discount factors (time preferences) for reasons explained in Section 3.2.2. Similar to Gerali et al. (2010) we assume that impatient consumers and entrepreneurs have smaller discount factors β_I and β_E than patient consumers β_P, which guarantees that patient consumers are net savers, whereas impatient consumers and entrepreneurs are net borrowers. Both types of consumers maximize discounted value of their expected utility subject to budget and borrowing constraints (for impatient consumers).

3.2.1 Patient consumers

The behavior of patient consumers can be represented as a two stage optimization: decision about consumption and saving and allocation of savings into banks. In the first stage patient households maximize their utility deciding on consumption labor and a portfolio of deposits given the sequence of budget constraints. They receive labor income ($W_{P,t}N_{P,t}$), deposits and interest earned in previous period ($R_t^d D_{t-1}^P$) and buy final goods ($C_{P,t}$), durable goods (housing) ($P_t^H H_{P,t}$), invest their savings in bank deposits (D_t^P).

The utility function of patient consumer j is

$$U_P = E_0 \sum_{t=0}^{\infty} \beta_P^t \left[(1-a_P)^{\sigma} \frac{(C_{P,t}(j) - a_P C_{P,t-1})^{1-\sigma}}{1-\sigma} e_t^c + h \frac{H_{P,t}(j)^{1-\zeta}}{1-\zeta} e_t^h - \frac{N_{P,t}(j)^{1+\phi}}{1+\phi} \right] \tag{1}$$

Subject to budget constraint

$$C_{P,t}(j) + D_t(j) + P_t^H H_{P,t}(j) = W_{P,t} N_{P,t}(j) + \frac{R_t^d}{\Pi_t} D_{t-1}(j) + P_t^H (1-\delta_h) H_{P,t-1}(j) + \Omega_{P,t}(j) - T_{P,t}(j) \tag{2}$$

Where R_t^d is gross return on deposits, $\Pi_t = P_t / P_{t-1}$ is the gross inflation, P_t^H is the price and δ_h is the depreciation rate of housing. e_t^c and e_t^h are common shocks that affect the behavior of both patient and Impatient consumers and represent preference shocks for consumption and housing, respectively. [1] Similar to Gerali et al. (2010) the term $(1-a_P)^{\sigma}$ is introduced to mute the effect of habit formation on the marginal utility of consumption in steady state.

3.2.2 Impatient consumers

Impatient consumers receive labor income ($W_{I,t}N_{I,t}$), take loans from banks ($L_{I,t}$) and buy final goods ($C_{I,t}$), durable goods (housing) ($P_t^H H_{I,t}$), pay back loans and interest of previous period

[1] A generic shock e_t follows AR(1) process with mean $\bar{e}$

$$e_t = (1-\rho_e)\,\bar{e} + \rho_e e_{t-1} + \varepsilon_t \tag{3}$$

where ρ_e is the autoregressive coefficient and ε_t is an i.i.d. zero mean normal random variable with standard deviation σ_e.

$(R^l_{I,t}L^I_{t-1})$.

$$U_I = E_0 \sum_{t=0}^{\infty} \beta_I^t \left[(1-a_I)^{\sigma} \frac{(C_{I,t}(j) - a_I C_{I,t-1})^{1-\sigma}}{1-\sigma} e_t^c + h \frac{H_{I,t}(j)^{1-\zeta}}{1-\zeta} e_t^h - \frac{N_{I,t}(j)^{1+\phi}}{1+\phi} \right] \tag{4}$$

Subject to budget constraint

$$C_{I,t}(j) + \frac{R_t^{l,I}}{\Pi_t} L_{t-1}^I(j) + P_t^H H_{I,t}(j) = W_{I,t} N_{I,t}(j) + L_{I,t}(j) + P_t^H (1-\delta_h) H_{I,t}(j) + \Omega_{I,t}(j) - T_{I,t}(j) \tag{5}$$

Where $R_t^{l,I}$ is gross cost of servicing loans. e_t^c and e_t^h are the same shocks as in case of Patient households.

Impatient consumers are assumed to face a borrowing constraint defined as a minimum loan-to value ratio over the expected value of undepreciated stock of housing.

$$E_t \left[\frac{R_{I,t+1}^l}{\Pi_{t+1}} L_{I,t}(j) \right] \leq E_t \left[m_t^I P_{t+1}^H (1-\delta_h) H_t^I(j) \right] \tag{6}$$

Here $m_{I,t}$ stands for Loan-to-Value ratio, which shows the ratio of loan and the value of the collateral. Generally Loan-to-Value ratio represents the credit policy of banks. It can be used by regulatory authorities as a macro-prudential tool to control the credit supply in the economy.

The assumption of lower discount factor $\beta_I < \beta_P$ guarantees that the constraint (6) is always binding in the neighborhood of the steady state. [2]

3.2.3 Entrepreneurs

Entrepreneurs hire labor from both patient $(N_{P,t})$ and $(N_{I,t})$ consumers, buy capital from capital producers $(P_t^K K_t)$ and produce intermediate goods (Y_t) according to Cobb-Douglas technology. They also take loans from banks $(L_{E,t})$, buy final consumption goods $(C_{E,t})$, pay back the loans and interest of the previous period $(R^l_{E,t}L^E_{t-1})$.

$$U_E = E_0 \sum_{t=0}^{\infty} \beta_E^t \left[(1-a_E)^{\sigma} \frac{(C_{E,t}(j) - a_E C_{E,t-1})^{1-\sigma}}{1-\sigma} \right]$$

Subject to budget constraint

$$C_{E,t}(j) + \frac{R_{E,t}^l}{\Pi_t} L_{t-1}^E(j) + W_{P,t} N_{P,t}(j) + W_{I,t} N_{I,t}(j) + P_t^K K_t(j) + \psi(u_t) K_{t-1}(j) =$$
$$= P_t^E Y_t(j) + L_{E,t}(j) + P_t^K (1-\delta_k) K_{t-1}(j) - T_{E,t}(j)$$

[2] For further reference see Iacoviello (2005)

Where $P_t^E = \frac{P_t^e}{P_t}$ is the relative price of intermediate goods with relation to price level.

Entrepreneurs produce intermediate goods according to Cobb-Douglas technology using capital with utilization rate u_t and labor from households.

$$Y_t(j) = A_t(u_t(j)K_{t-1}(j))^{\alpha} N_t^{1-\alpha}(j)$$

$$N_t = N_{P,t}^{\varsigma} N_{I,t}^{1-\varsigma}$$

Entrepreneurs are assumed to incur adjustment costs when they set capital utilization rate different from the steady state level. The term $\psi\left(u_t\right) K_{t-1}$ in Entrepreneur's budget constraint represents the costs associated with it. Following Christiano et al. (2005) the function $\psi(\cdot)$ has to satisfy the conditions $\psi(1) = 0$, meaning zero costs in steady state, $\psi'(1) > 0$ and $\psi''(1) > 0$. The functional form used in the model is

$$\psi\left(u_t\right) = \psi_1(u_t - 1) + \frac{\psi_2}{2}(u_t - 1)^2$$

Similar to Impatient households Entrepreneurs are constrained by minimum loan-to-value requirement, defined over the expected value of their undepreciated physical capital.

$$E_t\left[\frac{R^l_{E,t+1}}{\Pi_{t+1}} L_{E,t}(j)\right] \leq E_t\left[m_t^E P_{t+1}^K \left(1-\delta_k\right) K_t(j)\right]$$

Where $R_t^{l,E}$ is gross cost of servicing loans.

3.3 Financial intermediaries

Financial intermediaries act as specialists in financial markets and assist consumers in their decisions related to financial services. Simply they are mediators between consumers and banks, that are constructing deposit and loan portfolios consisting of both home and foreign currencies and sell to households.

3.3.1 Deposit intermediaries

Deposit intermediaries collect deposits from patient households, differentiate at no cost and invest in retail bank deposits.

$$\max E_0 \sum_{t=0}^{\infty} \beta_P^{t+1}\left[R_{t+1}^{d,h} D_t^h + R_{t+1}^{d,f} D_t^f - R_{t+1}^d D_t\right]$$

$$s.t. \qquad D_t = \left[\left(1-\xi_t^d\right)^{\frac{1}{\chi_d}} D_t^{h\,\frac{\chi_d - 1}{\chi_d}} + \xi_t^{d\,\frac{1}{\chi_d}} D_t^{f\,\frac{\chi_d - 1}{\chi_d}}\right]^{\frac{\chi_d}{\chi_d - 1}}$$

$R_t^{d,h}$ and $R_t^{d,f}$ are the gross returns on deposits

$$R_t^{d,h} = 1 + i_{t-1}^{d,h} \qquad R_t^{d,f} = \frac{S_t}{S_{t-1}}(1 + i_{t-1}^{d,f})$$

Note, that interest income of both types of deposits is known at the time of making deposits, whereas the pay-off of foreign-currency deposits is subject to changes due to exchange rate fluctuations and is observed only when deposits are being repaid back.

ξ_t^d is the share of foreign currency deposits in the aggregate index and has AR(1) representation. $\chi_d < 0$ is the elasticity of substitution between home- and foreign-currency deposits and follows an AR(1) process. This means, that households increase their holdings of foreign-currency deposits when they expect its pay off to increase and vice versa. Similarly they switch to home-currency deposits when they expect income from it to increase and vice versa.

D_t^h and D_t^f are Dixit-Stiglitz aggregates over the banks with stochastic elasticities of substitution $\varepsilon_t^{d,h}$ and $\varepsilon_t^{d,f}$ following AR(1) processes.

$$D_t^h = \left[\int_0^1 D_t^h(b)^{\frac{\varepsilon_t^{d,h}-1}{\varepsilon_t^{d,h}}} di\right]^{\frac{\varepsilon_t^{d,h}}{\varepsilon_t^{d,h}-1}} \qquad D_t^f = \left[\int_0^1 D_t^f(b)^{\frac{\varepsilon_t^{d,f}-1}{\varepsilon_t^{d,f}}} di\right]^{\frac{\varepsilon_t^{d,f}}{\varepsilon_t^{d,f}-1}}$$

Profit maximization yields the following demand schedules for home- and foreign-currency deposits

$$D_t^h = \left(1 - \xi_t^d\right)\left(E\left[\frac{R_{t+1}^{d,h}}{R_{t+1}^d}\right]\right)^{-\chi_d} D_t \qquad D_t^f = \xi_t^d \left(E\left[\frac{R_{t+1}^{d,f}}{R_{t+1}^d}\right]\right)^{-\chi_d} D_t \tag{7}$$

$$\max \quad \int_0^1 i_t^{ds}(b) D_t^s(b) dj - i_t^{ds} D_t^s$$

$$s.t. \left[\int_0^1 D_t^s(b)^{\frac{\varepsilon_t^d-1}{\varepsilon_t^d}} di\right]^{\frac{\varepsilon_t^d}{\varepsilon_t^d-1}} = D_t^s$$

3.3.2 Loan intermediaries

Loan intermediaries take loans from banks, repackage them in a Dixit-Stiglitz aggregator and sell to impatient households and entrepreneurs. They maximize discounted value of future profits by choosing $L_{q,t}^h$ and $L_{q,t}^f$ subject to loan aggregator constraint

$$\max E_0 \sum_{t=0}^{\infty} \beta_q^{t+1} \left[R_{t+1}^{l,q} L_t^q - R_{t+1}^{l,qh} L_{q,t}^h - R_{t+1}^{l,qf} L_{q,t}^f\right]$$

$$s.t. \qquad \left[(1 - \xi_t^q)^{\frac{1}{\chi_l}} L_t^{qh\,\frac{\chi_l-1}{\chi_l}} + \xi_t^{q\,\frac{1}{\chi_l}} L_t^{qf\,\frac{\chi_l-1}{\chi_l}}\right]^{\frac{\chi_l}{\chi_l-1}} = L_t^q$$

Where ξ_t^l is the share of foreign currency loans in the aggregate index and has AR(1) representation. $\chi_t^l > 0$ is the elasticity of substitution between home- and foreign-currency loans and is an AR(1) process.

$L_{q,t}^h$ and $L_{q,t}^f$ are aggregates over the banks

$$L_{q,t}^h = \left[\int_0^1 L_{q,t}^h(b)^{\frac{\varepsilon_t^{l,h}-1}{\varepsilon_t^{l,h}}} di \right]^{\frac{\varepsilon_t^{l,h}}{\varepsilon_t^{l,h}-1}} \qquad L_{q,t}^f = \left[\int_0^1 L_{q,t}^f(b)^{\frac{\varepsilon_t^{l,h}-1}{\varepsilon_t^{l,h}}} di \right]^{\frac{\varepsilon_t^{l,h}}{\varepsilon_t^{l,h}-1}}$$

$R_{q,t}^{l,h}$ and $R_{q,t}^{l,f}$ are the gross costs on loans

$$R_{q,t}^{l,h} = 1 + i_{q,t-1}^{l,h} \qquad R_{q,t}^{l,f} = \frac{S_t}{S_{t-1}}(1 + i_{q,t-1}^{l,f})$$

Profit maximization yields the following demand schedules for home- and foreign-currency loans

$$L_t^{qh} = (1-\xi) \left(E \left[\frac{R_{q,t+1}^{l,h}}{R_{q,t+1}^l} \right] \right)^{-\chi_l} L_t^q \qquad L_t^{qf} = \xi \left(E \left[\frac{R_{q,t+1}^{l,f}}{R_{q,t+1}^l} \right] \right)^{-\chi_l} L_t^q$$

$$\max \quad i_t^{l,qs} L_t^{qs} - \int_0^1 i_t^{l,qs}(b) L_t^{qs}(b) dj$$

$$s.t. \left[\int_0^1 L_t^{qs}(b)^{\frac{\varepsilon_l - 1}{\varepsilon_l}} di \right]^{\frac{\varepsilon_l}{\varepsilon_l - 1}} = L_t^{qs}$$

3.4 Banks

There is continuum of banks indexed by b. Banks stand in between impatient consumers, entrepreneurs and patient consumers acting as financial intermediaries between them. They operate in a monopolistically competitive market as in Gerali et al. (2010). Each bank consists of deposit branch, loan branch and wholesale branch. The structure of a representative bank in the model is depicted in Figure 2.

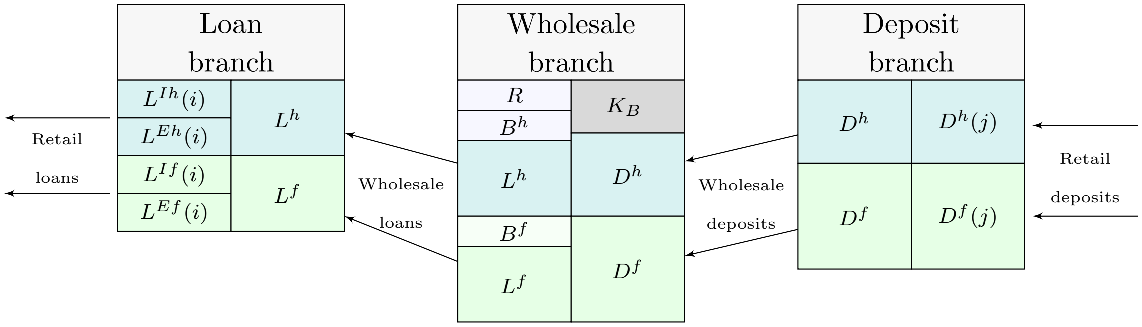

Figure 2: The structure of a representative bank in the model

Wholesale branch of each bank operates in a competitive market, whereas retail branches operate in monopolistically competitive markets. Retail branches also incur adjustment costs when they change interest rates, which induces short-run stickiness in retail rates.

3.4.1 Wholesale branches

Wholesale branch operates in a competitive market choosing the size and composition of its balance sheet. It holds capital ($K_{B,t}$), wholesale deposits (D_t^h and D_t^f) and net foreign interbank borrowing (B_t^f) in the liability side of its balance sheet and provides wholesale loans (L_t^h and L_t^f) to loan branches reflected in the asset side. It also has to satisfy the capital requirement ratio ν set by monetary authorities and is assumed to incur costs when deviates from that level.

Wholesale branch obtains wholesale deposits in home and foreign currencies at wholesale interest rates $r_t^{d,h}$ and $r_t^{d,f}$ and lends funds to loan branch at wholesale interest rate $r_t^{l,h}$ and $r_t^{l,f}$ for home and foreign currencies, respectively. It can lend or borrow funds in foreign interbank market at interest rate $i_{H,t-1}^f$ to hedge against foreign exchange risk.

Wholesale branch maximizes the discounted sum of future cash flows subject to the balance sheet constraint and restriction on FX position.

$$\begin{aligned}\max E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \Bigg[& \frac{1+r_{t-1}^{l,h}}{\Pi_t} L_{t-1}^h - L_t^h + \frac{S_t}{S_{t-1}} \frac{1+r_{t-1}^{l,f}}{\Pi_t} L_{t-1}^f - L_t^f + \frac{1+r_{t-1}^{d,h}}{\Pi_t} D_{t-1}^h + D_t^h - \\ & - \frac{S_t}{S_{t-1}} \frac{1+r_{t-1}^{l,f}}{\Pi_t} D_{t-1}^f + D_t^f - \frac{S_t}{S_{t-1}} \frac{1+i_{H,t-1}^f}{\Pi_t} IB_{t-1}^f + IB_t^f - \\ & - \frac{\kappa_B^K}{2} \left(\frac{K_{B,t-1}}{L_{t-1}} - \nu \right)^2 K_{B,t-1} \Bigg] \end{aligned} \tag{8}$$

$$\begin{aligned} s.t. \qquad L_t &= L_t^h + L_t^f \\ D_t &= D_t^h + D_t^f \\ L_t &= K_{B,t} + D_t + B_t^f \end{aligned}$$

Optimality conditions establish the following relationships between interest rates and bank capital premium τ_t

$$\begin{aligned} 1+r_t^{l,h} &= \frac{S_{t+1}}{S_t}\left(1+r_t^{l,f}\right) & \qquad 1+r_t^{d,h} &= \frac{S_{t+1}}{S_t}\left(1+r_t^{d,f}\right) \\ r_t^{l,h} &= r_t^{d,h}+\tau_t & r_t^{l,f} &= r_t^{d,f}+E_t\left[\frac{S_t}{S_{t+1}}\right]\tau_t \end{aligned} \tag{9}$$

Bank capital premium

$$\tau_t = -\kappa_B^K\left(\frac{K_{B,t-1}}{L_{t-1}}-\nu\right)\left(\frac{K_{B,t-1}}{L_{t-1}}\right)^2 \tag{10}$$

Bank capital is accumulated as the sum of capital of previous period plus net profit of banks

$$K_{B,t} = (1-\delta_B)\, K_{B,t-1} e_{B,t}^K + J_t \tag{11}$$

Overall bank profits are the sum of net earnings of wholesale and retail branches. After canceling in-bank flows the profit of bank b is

$$\begin{aligned} J_t(b) = {} & \frac{1+i_{I,t-1}^{l,h}(b)}{\Pi_t} L_{I,t-1}^h(b) - L_{I,t-1}^h(b) + \frac{S_t}{S_{t-1}}\frac{1+i_{I,t-1}^{l,f}(b)}{\Pi_t} L_{I,t-1}^f(b) - L_{I,t-1}^f(b) + \\ & + \frac{1+i_{E,t-1}^{l,h}(b)}{\Pi_t} L_{E,t-1}^h(b) - L_{E,t-1}^h(b) + \frac{S_t}{S_{t-1}}\frac{1+i_{E,t-1}^{l,f}(b)}{\Pi_t} L_{E,t-1}^f(b) - L_{E,t-1}^f(b) + \\ & - \frac{1+i_{t-1}^{d,h}(b)}{\Pi_t} D_{t-1}^h(b) + D_{t-1}^h(b) - \frac{S_t}{S_{t-1}}\frac{1+i_{t-1}^{l,f}(b)}{\Pi_t} D_{t-1}^f(b) + D_{t-1}^f(b) - \\ & - \frac{S_t}{S_{t-1}}\frac{1+i_{H,t-1}^{f}(b)}{\Pi_t} B_{t-1}^f(b) + B_t^f(b) - \frac{\kappa_B^K}{2}\left(\frac{K_{B,t-1}(b)}{L_{t-1}(b)}-\nu\right)^2 K_{B,t-1} - Adj_t(b) \end{aligned} \tag{12}$$

$Adj_t(b)$ stands for adjustment costs of loan and deposit branches for changing retail interest rates

$$\begin{aligned} Adj_t = {} & \frac{\kappa^{d,h}}{2}\left(\frac{i_t^{d,h}(b)}{i_{t-1}^{d,h}(b)}-1\right)^2 i_t^{d,h} D_t^h + \frac{\kappa_I^{l,h}}{2}\left(\frac{i_{I,t}^{l,h}(b)}{i_{I,t-1}^{l,h}(b)}-1\right)^2 i_{I,t}^{l,h} L_{I,t}^h + \frac{\kappa_E^{l,h}}{2}\left(\frac{i_{E,t}^{l,h}(b)}{i_{E,t-1}^{l,h}(b)}-1\right)^2 i_{E,t}^{l,h} L_{E,t}^h + \\ & + \frac{\kappa^{d,f}}{2}\left(\frac{i_t^{d,f}(b)}{i_{t-1}^{d,f}(b)}-1\right)^2 i_t^{d,f} D_t^f + \frac{\kappa_I^{l,f}}{2}\left(\frac{i_{I,t}^{l,f}(b)}{i_{I,t-1}^{l,f}(b)}-1\right)^2 i_{I,t}^{l,f} L_{I,t}^f + \frac{\kappa_E^{l,f}}{2}\left(\frac{i_{E,t}^{l,f}(b)}{i_{E,t-1}^{l,f}(b)}-1\right)^2 i_{E,t}^{l,f} L_{E,t}^f \end{aligned} \tag{13}$$

3.4.2 Deposit branches

Deposit branch collects retail deposits from consumers and pass them to the wholesale branch as wholesale deposits. Operating in a monopolistically competitive market, deposit branch of each bank j sets retail deposit rates (i_t^d) maximizing expected value of future profits subject to upward sloping deposit supply curve of patient consumers. We also assume that each deposit branch incurs quadratic adjustment costs when it changes its retail interest rate. Without loss of generality, we assume, that there are two separate branches for home- and foreign-currency deposits. The problem for home-currency deposit branch is

$$\max_{\{i_t^{d,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\frac{1 + r_{t-1}^{d,h}(b)}{\Pi_t} D_{t-1}^h(b) - D_t^h(b) - \frac{1 + i_{t-1}^{d,h}(b)}{\Pi_t} D_{t-1}^h(b) + D_t^h(b) - \right.$$
$$\left. - \frac{\kappa^{d,h}}{2} \left(\frac{i_t^{d,h}(b)}{i_{t-1}^{d,h}(b)} - 1 \right)^2 i_t^{d,h} D_t^h \right]$$

$$s.t. \qquad D_t^h(b) = \left(\frac{i_t^{d,h}(b)}{i_t^{d,h}} \right)^{-\varepsilon_t^{d,h}} D_t^h$$

After a simplification the deposit branch's problem reduces to

$$\max_{\{i_t^{d,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\frac{r_{t-1}^{d,h}(b)}{\Pi_t} D_{t-1}^h(b) - \frac{i_{t-1}^{d,h}(b)}{\Pi_t} D_{t-1}^h(b) - \frac{\kappa^{d,f}}{2} \left(\frac{i_t^{d,p}(b)}{i_{t-1}^{d,p}(b)} - 1 \right)^2 i_t^{d,p} D_t^p \right]$$

The problem for foreign-currency deposit branch is

$$\max_{\{i_t^{d,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\frac{S_t}{S_{t-1}} \frac{1 + r_{t-1}^{d,f}(b)}{\Pi_t} D_{t-1}^f(b) - D_t^f(b) - \frac{S_t}{S_{t-1}} \frac{1 + i_{t-1}^{d,f}(b)}{\Pi_t} D_{t-1}^f(b) + D_t^f(b) - \right.$$
$$\left. - \frac{\kappa^{d,f}}{2} \left(\frac{i_t^{d,f}(b)}{i_{t-1}^{d,f}(b)} - 1 \right)^2 i_t^{d,f} D_t^f \right]$$

$$s.t. \qquad D_t^f(b) = \left(\frac{i_t^{d,f}(b)}{i_t^{d,f}} \right)^{-\varepsilon_t^{d,f}} D_t^f$$

After a simplification the deposit branch's problem reduces to

$$\max_{\{i_t^{d,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\frac{S_t}{S_{t-1}} \frac{r_{t-1}^{d,f}(b)}{\Pi_t} D_{t-1}^f(b) - \frac{S_t}{S_{t-1}} \frac{i_{t-1}^{d,f}(b)}{\Pi_t} D_{t-1}^f(b) - \frac{\kappa^{d,f}}{2} \left(\frac{i_t^{d,p}(b)}{i_{t-1}^{d,p}(b)} - 1 \right)^2 i_t^{d,p} D_t^p \right]$$

3.4.3 Loan branches

Loan branch obtains wholesale deposits from wholesale branch at wholesale rates, differentiates them at no cost and lends to Impatient consumers ($L_{I,t}$) and Entrepreneurs ($L_{E,t}$). Operating in a monopolistically competitive market, loan branch of each bank j sets retail interest rates (i_t^l)

maximizing expected value of future profits subject to downward sloping loan demand curve of impatient consumers. We also assume that each loan branch incurs quadratic adjustment costs when it changes its retail interest rate. Without loss of generality, we assume, that there are two separate branches for home- and foreign-currency loans. The problem for home-currency loan branch is

$$\max_{\{i_t^{lp,I},i_{E,t}^{l,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \Bigg[\frac{1+i_{I,t-1}^{l,h}(b)}{\Pi_t} L_{I,t-1}^h(b) - L_{I,t}^h(b) + \frac{1+i_{E,t-1}^{l,h}(b)}{\Pi_t} L_{E,t-1}^h(b) - L_{E,t}^h(b) -$$
$$- \frac{1+r_{t-1}^{l,h}(b)}{\Pi_t} L_{t-1}^h(b) + L_t^h(b) - \frac{\kappa_I^{l,h}}{2} \left(\frac{i_{I,t}^{l,h}(b)}{i_{I,t-1}^{l,h}(b)} - 1 \right)^2 i_{I,t}^{l,h} L_{I,t}^h - \frac{\kappa_E^{l,h}}{2} \left(\frac{i_{E,t}^{l,h}(b)}{i_{E,t-1}^{l,h}(b)} - 1 \right)^2 i_{E,t}^{l,h} L_{E,t}^h \Bigg]$$

$$s.t. \qquad L_{I,t}^h(b) = \left(\frac{i_{I,t}^{l,h}(b)}{i_{I,t}^{l,h}} \right)^{-\varepsilon_{I,t}^{l,h}} L_{I,t}^h \qquad L_{E,t}^h(b) = \left(\frac{i_{E,t}^{l,h}(b)}{i_{E,t}^{l,h}} \right)^{-\varepsilon_{E,t}^{l,h}} L_{E,t}^h$$
$$L_{I,t}^h + L_{E,t}^h = L_t^h$$

After simplification

$$\max_{\{i_t^{lp,I},i_{E,t}^{l,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \Bigg[\frac{i_{I,t-1}^{l,h}(b)}{\Pi_t} L_{I,t-1}^h(b) + \frac{i_{E,t-1}^{l,h}(b)}{\Pi_t} L_{E,t-1}^h(b) - \frac{r_{t-1}^{l,h}(b)}{\Pi_t} L_{t-1}^h(b) -$$
$$- \frac{\kappa_I^{l,h}}{2} \left(\frac{i_{I,t}^{l,h}(b)}{i_{I,t-1}^{l,h}(b)} - 1 \right)^2 i_{I,t}^{l,h} L_{I,t}^h - \frac{\kappa_E^{l,h}}{2} \left(\frac{i_{E,t}^{l,h}(b)}{i_{E,t-1}^{l,h}(b)} - 1 \right)^2 i_{E,t}^{l,h} L_{E,t}^h \Bigg]$$

The problem for foreign-currency loan branch is

$$\max_{\{i_t^{lp,I},i_{E,t}^{l,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \Bigg[\frac{S_t}{S_{t-1}} \frac{1+i_{I,t-1}^{l,f}(b)}{\Pi_t} L_{I,t-1}^f - L_{I,t}^f(b) + \frac{S_t}{S_{t-1}} \frac{1+i_{E,t-1}^{l,f}(b)}{\Pi_t} L_{E,t-1}^f(b) - L_{E,t}^f(b) -$$
$$- \frac{S_t}{S_{t-1}} \frac{1+r_{t-1}^{l,f}(b)}{\Pi_t} L_{t-1}^f(b) + L_t^f(b) -$$
$$- \frac{\kappa_I^{l,f}}{2} \left(\frac{i_{I,t}^{l,f}(b)}{i_{I,t-1}^{l,f}(b)} - 1 \right)^2 i_{I,t}^{l,f} L_{I,t}^f - \frac{\kappa_E^{l,f}}{2} \left(\frac{i_{E,t}^{l,f}(b)}{i_{E,t-1}^{l,f}(b)} - 1 \right)^2 i_{E,t}^{l,f} L_{E,t}^f \Bigg]$$

$$s.t. \qquad L_{I,t}^f(b) = \left(\frac{i_{I,t}^{l,f}(b)}{i_{I,t}^{l,f}} \right)^{-\varepsilon_{I,t}^{l,h}} L_{I,t}^f \qquad L_{E,t}^f(b) = \left(\frac{i_{E,t}^{l,f}(b)}{i_{E,t}^{l,f}} \right)^{-\varepsilon_{E,t}^{l,h}} L_{E,t}^f$$
$$L_{I,t}^f + L_{E,t}^f = L_t^f$$

After simplification

$$\max_{\{i_t^{lp,I}, i_{E,t}^{l,p}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{P} \left[\frac{S_t}{S_{t-1}} \frac{i_{I,t-1}^{l,f}(b)}{\Pi_t} L_{I,t-1}^{f}(b) + \frac{S_t}{S_{t-1}} \frac{i_{E,t-1}^{l,f}(b)}{\Pi_t} L_{E,t-1}^{f}(b) - \frac{S_t}{S_{t-1}} \frac{r_{t-1}^{l,f}(b)}{\Pi_t} L_{t-1}^{f}(b) - \right.$$
$$\left. -\frac{\kappa_I^{l,f}}{2} \left(\frac{i_{I,t}^{l,f}(b)}{i_{I,t-1}^{l,f}(b)} - 1 \right)^2 i_{I,t}^{l,f} L_{I,t}^{f} - \frac{\kappa_E^{l,f}}{2} \left(\frac{i_{E,t}^{l,f}(b)}{i_{E,t-1}^{l,f}(b)} - 1 \right)^2 i_{E,t}^{l,f} L_{E,t}^{f} \right]$$

3.5 Goods producing sector

3.5.1 Capital producers

Similar to Gerali et al. (2010), we assume that the beginning of each period, each capital good producer buys final goods from Final goods producers, buys the stock of old undepreciated capital from entrepreneurs at nominal price P_t^K, and produces new capital according to transformation technology characterized by quadratic adjustment costs.

$$\max_{I_t^K(k)} E_0 \sum_{i=0}^{\infty} \Lambda_{0,t}^{E} \left[P_t^K \left(K_t(k) - (1-\delta_k) K_{t-1}(k) \right) - I_t^K(k) \right]$$

$$s.t. \qquad K_t(k) = (1-\delta_k) K_{t-1}(k) + \left(1 - \frac{\kappa_k}{2} \left(\frac{I_t^K(k)}{I_{t-1}^K(k)} e_t^{ik} - 1 \right)^2 \right) I_t^K(k)$$

3.5.2 Housing producers

Similar to Brzoza-Brzezina and Makarski (2011), we assume that the beginning of each period, each housing producer buys final goods from Final goods producers, buys the stock of old undepreciated housing from households at nominal price P_t^H, and produces new housing according to transformation technology characterized by quadratic adjustment costs.

$$\max_{I_t^H(h)} E_0 \sum_{i=0}^{\infty} \Lambda_{0,t}^{E} \left[P_t^H \left(H_t(h) - (1-\delta_h) H_{t-1}(h) \right) - I_t^H(h) \right]$$

$$s.t. \qquad H_t(h) = (1-\delta_h) H_{t-1}(h) + \left(1 - \frac{\kappa_h}{2} \left(\frac{I_t^H(h)}{I_{t-1}^H(h)} e_t^{ih} - 1 \right)^2 \right) I_t^H(h)$$

3.5.3 Retail goods producers

Retailer operate in a monopolistically competitive market and act as "branders". They buy intermediate goods from Entrepreneurs at price P_E differentiate them at no cost and sell to final goods producers at price $P_t^h(i)$ subject to the demand schedule for their good. Retailers are assumed to incur quadratic adjustment costs a là Rotemberg.

$$\max_{\{P_t\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\frac{P_t^h(i)}{P_t^h} Y_t^h(i) - \frac{P_t^e}{P_t^h} Y_t^h(i) - \frac{\kappa_r}{2} \left(\frac{P_t^h(i)}{P_{t-1}^h(i)} - \Pi_{ss}^{h\ 1-\theta} \Pi_{t-1}^{h\ \theta} \right)^2 Y_t^h \right]$$

$$s.t. \qquad Y_t^h(i) = \left(\frac{P_t^h(i)}{P_t^h} \right)^{-\varepsilon_t^y} Y_t^h$$

3.5.4 Importers

Importers buy foreign goods and sell in domestic market. We assume monopolistic competition in import market, which means that importers sell imported goods applying a markup over international prices. Importers also incur price adjustment costs, which induces deviations from law of one price in the short run.

$$\max_{\{P_t^m\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\frac{P_t^m(i)}{P_t^m} M_t(i) - \frac{S_t P_{F,t}^f}{P_t^m} M_t(i) - \frac{\kappa_r}{2} \left(\frac{P_t^m(i)}{P_{t-1}^m(i)} - \Pi_{ss}^{m\ 1-\theta} \Pi_{t-1}^{m\ \theta} \right)^2 M_t \right]$$

$$s.t. \qquad M_t(i) = \left(\frac{P_t^m(i)}{P_t^m} \right)^{-\varepsilon_t^y} M_t$$

3.5.5 Final goods producers

Perfectly competitive Final goods producers package domestically produced and imported goods and sell them in final goods market. Formally their problem is

$$\max P_t Y_t^H - P_t^h Y_t^h - P_t^m M_t \tag{14}$$

Where $Y_{H,t}$ is defined as a Dixit-Stiglitz aggregator over domestically produced and imported goods with home bias parameter of ω and elasticity of substitution η.

$$Y_t^H = \left[(1-\omega)^{\frac{1}{\eta}} Y_t^{h\ \frac{\eta-1}{\eta}} + \omega^{\frac{1}{\eta}} M_t^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

$$Y_t^h = \left[\int_0^1 Y_t^h(i)^{\frac{\varepsilon_t^y - 1}{\varepsilon_t^y}} di \right]^{\frac{\varepsilon_t^y}{\varepsilon_t^y - 1}} \qquad M_t = \left[\int_0^1 M_t(i)^{\frac{\varepsilon_t^m - 1}{\varepsilon_t^m}} di \right]^{\frac{\varepsilon_t^m}{\varepsilon_t^m - 1}}$$

Profit maximization of Final goods producers yields the following demand schedules for domestic and imported goods

$$Y_t^h = (1-\omega) \left(\frac{P_t^h}{P_t} \right)^{-\eta} Y_t^H \qquad M_t = \omega \left(\frac{P_t^m}{P_t} \right)^{-\eta} M_t$$

Where aggregate price level is defied as

$$P_t = \left[(1-\omega)\, P_t^{h\,1-\eta} + \omega P_t^{m\,1-\eta} \right]^{\frac{1}{1-\eta}} \tag{15}$$

Demand for i th good

$$Y_t^h(i) = \left(\frac{P_t^h(i)}{P_t^h} \right)^{-\varepsilon_t^y} Y_t^h \qquad M_t(i) = \left(\frac{P_t^m(i)}{P_t^m} \right)^{-\varepsilon_t^m} M_t$$

Aggregate domestic and imported goods prices

$$P_t^h = \left(\int_0^1 P_t^h(i)^{1-\varepsilon_t^y} \right)^{\frac{1}{1-\varepsilon_t^y}} \qquad P_t^m = \left(\int_0^1 P_t^m(i)^{1-\varepsilon_t^m} \right)^{\frac{1}{1-\varepsilon_t^m}}$$

From (15) CPI inflation takes the form

$$\Pi_t = \left[(1-\omega) \left(\Pi_t^h P_{H,t-1} \right)^{1-\eta} + \omega (\Pi_t^m P_{M,t-1})^{1-\eta} \right]^{\frac{1}{1-\eta}} \tag{16}$$

Where $P_{H,t}$ and $P_{F,t}$ are relative prices of domestically produced and imported goods with respect to price level and are defined in (24).

3.6 Government and Monetary policy

The government consumes a constant proportion of output. Government expenditures are financed by lump-sum taxes levied on households and entrepreneurs. It runs a balanced budget

$$G_t = \varpi Y_t \tag{17}$$

$$G_t = T_t e_t^g \tag{18}$$

Where e_t^g is government consumption shock and follows an AR(1) process.

The baseline monetary policy rule has the form of Taylor rule

$$1 + i_t^h = \left(1 + i_{t-1}^h\right)^{\rho_h^i} \left(\left(1 + i^h\right) \left(\frac{\Pi_t}{\Pi_{ss}} \right)^{\phi_\Pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\phi_Y} \right)^{1-\rho_h^i} e_t^m \tag{19}$$

Where i^h is neutral level of monetary policy interest rate, ρ_t^i is interest rate smoothing parameter, ϕ_Π and ϕ_Y are monetary policy reaction coefficients to inflation and output growth.

In the paper an alternative monetary policy rule is analyzed in which the policy partially reacts to exchange rate movements. Namely the rule is given by

$$1 + i_t^h = \left(1 + i_{t-1}^h\right)^{\rho_h^i} \left(\left(1 + i^h\right) \left(\frac{\Pi_t}{\Pi_{ss}}\right)^{\phi_\Pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_Y} \left(\frac{S_t}{S_{t-1}}\right)^{\phi_S}\right)^{1-\rho_h^i} e_t^m \tag{20}$$

3.7 Open economy relations

Terms of trade is defined as the ratio of domestically produced and imported goods

$$T_t = \frac{P_t^m}{P_t^h} \tag{21}$$

Low-of-one price gap

$$\Psi_t = \frac{S_t P_{F,t}^f}{P_t^m} \tag{22}$$

Using Equations (21) and (22)

$$\frac{\Psi_t}{\Psi_{t-1}} = \frac{S_t}{S_{t-1}} \frac{\Pi_t^f}{\Pi_t^m} \tag{23}$$

Using the definition of price level in home country (15) we define relative prices of domestically produced and imported goods with respect to price level as follows

$$P_{H,t} \equiv \frac{P_t^h}{P_t} = \left((1-\omega) + \omega {T_t}^{1-\eta}\right)^{\frac{1}{\eta-1}} \tag{24}$$

$$P_{M,t} \equiv \frac{P_t^m}{P_t} = \left((1-\omega) {T_t}^{\eta-1} + \omega\right)^{\frac{1}{\eta-1}} \tag{25}$$

Assuming that the law of one price holds in export sector, $P_t^h = S_t P_{F,t}^h$, the relative price of domestically produced goods in relation to foreign gods can be derived from the definition of real exchange rate and relative price of domestic goods.

$$P_{F,t} \equiv \frac{P_{F,t}^h}{P_{F,t}^f} = \frac{P_{H,t}}{Q_t} \tag{26}$$

It follows from the definition of the real exchange rate

$$Q_t = \frac{S_t P_{F,t}^f}{P_t} = \Psi_t P_{M,t} \tag{27}$$

The foreign demand for domestically produced goods is assumed to be

$$X_{H,t}(i) = \left(\frac{P_{F,t}^h(i)}{P_{F,t}^h}\right)^{-\varepsilon_t^y} X_{H,t} \qquad X_{H,t} = \omega^* \left(\frac{P_{F,t}^h}{S_t P_{F,t}^f}\right)^{-\eta_f} Y_{F,t} \tag{28}$$

The model is closed by the debt-elastic interest rate approach of Schmitt-Grohé and Uribe (2003). We assume that the gross foreign interest rate is equal to foreign monetary policy rate multiplied by a country risk premium. [3] Foreign monetary policy rate $i^f_{F,t}$ is assumed to follow an AR(1) process.

$$1 + i^f_{H,t} = \Phi_t \left(1 + i^f_{F,t}\right)$$

The risk premium Φ_t is an increasing function of the country's indebtedness and is subject to stochastic shocks e^{Φ}_t

$$\Phi_t = exp(\varrho \frac{P_t Debt_t}{P^h_t Y_t}) e^{\Phi}_t \tag{29}$$

Where $Debt_t$ is the sum of international debt of real and financial sectors of the economy (Γ_t and B^f_t respectively) at time t, and ϱ is a risk premium parameter. Note that the premium is equal to one when the country has no debt, and is greater than one for positive values of debt.

Then Uncovered interest rate parity condition implies

$$1 + i^h_t = E_t \left[\frac{S_{t+1}}{S_t}\right] \left(1 + i^f_{H,t}\right) e^{UIP}_t \tag{30}$$

Where e^{UIP}_t is a UIP shock.

3.8 Aggregation and market clearing

Balance of Payments in (nominal) terms of home currency

$$\begin{aligned} &\int_0^1 S_t P^h_{F,t}(i) X_{H,t}(i) di + S_t \Gamma^*_t + S_t I B^*_t + S_t P^f_{F,t} \Omega = \\ &= \int_0^1 S_t P^f_{F,t}(i) M_{H,t}(i) di + \left(1 + i^f_{H,t}\right) S_t \Gamma^*_{t-1} + \left(1 + i^f_{H,t}\right) S_t I B^*_{t-1} \end{aligned} \tag{31}$$

Where Γ^* and B^*_t are the foreign debt and interbank borrowing in foreign (nominal) currency.

Balance of Payments in real terms of home currency

$$P_{H,t} X_{H,t} + \Gamma_t + I B_t + Q_t \Omega_t = Q_t M_{H,t} + \frac{R^f_{H,t}}{\Pi_t} \Gamma_{t-1} + \frac{R^f_{H,t}}{\Pi_t} I B_{t-1} \tag{32}$$

Where

$$R^f_{H,t} = \frac{S_t}{S_{t-1}} \left(1 + i^f_{H,t}\right) \qquad P_t \Gamma_t = S_t \Gamma^*_t \qquad P_t B^f_t = S_t B^*_t$$

with Γ and B^f_t being foreign debt and interbank borrowing in domestic real terms.

Aggregate consumption is equal to sum of patient, impatient households' and entrepre-neurs'

[3] A similar approach was taken in Brzoza-Brzezina and Makarski (2011)

consumptions weighted by their relative weights $\gamma_P + \gamma_I + \gamma_E = 1$

$$C_t = \gamma_P C_{P,t} + \gamma_I C_{I,t} + \gamma_E C_{E,t}$$

Aggregate domestic absorption

$$P_t Y_{H,t} = P_t C_t + P_t I_t^K + P_t I_t^H + P_t G_t$$

Where G_t are government expenditures financed by lump-sum taxes levied on households and entrepreneurs. We assume that G_t follows an AR(1) process.

National income identity in nominal terms

$$P_t^h Y_t = P_t Y_{H,t} + P_t^h X - P^m M_t$$

Expressing in real terms

$$Y_t = \frac{Y_t^H}{P_{H,t}} + X - T_t M$$

Housing market clearing condition

$$\gamma_P H_{P,t} + \gamma_I H_{I,t} = H_{t-1}$$

$$T_t = \gamma_P T_{P,t} + \gamma_I T_{I,t} + \gamma_E T_{E,t}$$

4 Estimation

The model is estimated for Armenia an emerging economy with significant amount of dollarization. Several models have been developed for Armenia extending standard New-Keynesian frameworks to include import sector and remittances Mkrtchyan et al. (2009), labor market Barseghyan (2013) etc..

The estimation is done using Bayesian methods. Some of the parameters defining the steady state of the model are calibrated in a way to match the observed levels in the data. The parameters influencing the dynamics of the model are estimated.

4.1 Data

The Model is estimated for Armenia using quarterly data series spanning the period from 2004 to 2014. The data were collected from the Central bank of Armenia. Data on real output, monetary policy interest rate, inflation, nominal and real exchange rates, retail home and foreign currency deposit and loan interest rates, deposits, household loans, business loans, deposit dollarization rate, household and business dollarization rates are used.

The data on deposits and loans are deflated using Consumer price index. The data on output, deposits, loans and nominal exchange rate are taken with natural logs. All variables are seasonally adjusted using Census X12 ARIMA method and are detrended by one-sided Hodrick-Prescott filter (using Kalman filter approach).

The data used for estimation are represented in Figure 3

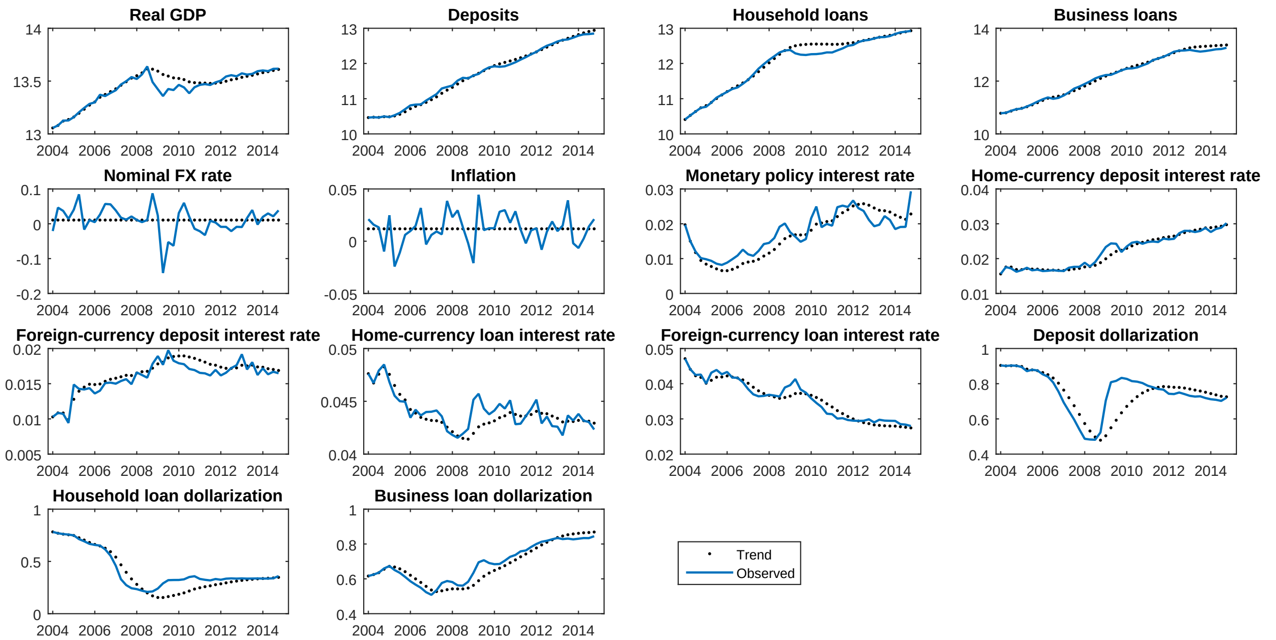

Figure 3: Data used for estimation

4.2 Calibrated parameters

The parameters determining the steady state of the model are calibrated to match the average levels in the data. β_P is set to 0.99 reflecting the average deposit interest rate of . ξ_d is calibrated to 0.65 which corresponds to the average dollarization rate in the sample. Similarly ξ_{lI} and ξ_{lE} are calibrated to 0.6 and 0.6 for household and business loans dollarization rates, respectively. ϵ_d is set to -5 to match the observed average spread between monetary policy rate and short term deposit rates. Similarly ϵ_l is set to 2.5 according to the spread between monetary policy rate and short term loan rates. The equilibrium bank capital adequacy rate is calibrated to ν above the regulatory level of 0.12. The share of capital in the production function is calibrated to 0.6 based on observed shares of capital and labor in national income distribution obtained from the income approach of calculating GDP. The home country openness parameter ω is set to 0.4 to match the average observed import / consumption ratio in the sample. Elasticity of substitution between labor services is set to 3 based on Barseghyan (2013) estimate of 2.99.

The habit parameter $a_P = a_I = a_E$ is calibrated at 0.5 based on the estimate of 0.49 in Barseghyan (2013) and the value of 0.65 in Mkrtchyan et al. (2009). The inverse of elasticity of intertemproral substitution σ is calibrated at 1.5 according to the value of 1.86 in Mkrtchyan et al. (2009) and the estimate of 1.33 in Barseghyan (2013).

Parameter	Value	Description
Households		
β_P	0.99	Discount factor of patient consumers
β_I	0.95	Discount factor of impatient consumers
β_E	0.95	Discount factor of entrepreneurs
σ	1.5	Inverse of elasticity of intertemproral substitution for consumption
ζ	1	Inverse of elasticity of intertemproral substitution for housing
ϕ	1	Inverse Frisch elasticity of labor supply
a	0.5	Habit parameter
Financial intermediaries and Banks		
ξ_d	0.65	Deposit dollarization
$\xi_{I,l}$	0.6	Impatient households loan dollarization
$\xi_{E,l}$	0.6	Entrepreneurs loan dollarization
ϵ_d	-5	Elasticity of substitution between banks for deposits
ϵ_l	2.5	Elasticity of substitution between banks for loans
m_I	0.5	Loan-to-Value ratio for Impatient consumers
m_E	0.35	Loan-to-Value ratio for Entrepreneurs
ν	0.15	Bank capital requirement
Production sector		
α	0.35	The share of capital in the production function
δ_k	0.025	Physical capital depreciation rate
δ_h	0.01	Housing depreciation rate
ς	0.6	Patient households share in labor
ε_y	6	Elasticity of substitution between domestic goods
ε_m	6	Elasticity of substitution between imported goods
ε_n	3	Elasticity of substitution between labor services
Open economy relations		
ω	0.4	Home country openness
η	0.75	Elasticity of substitution between home and foreign goods
ϱ	0.005	Country risk premium parameter

Table 1: Calibrated parameters

4.3 Prior distributions

As there is very limited evidence about the model parameters from previous works, we use loose priors for both structural parameters and standard deviations of shocks. We follow a general principle of setting standard deviations of priors at 30% of their values.

Whenever possible, prior distributions are formed using statistical evidence from previous works. Mkrtchyan et al. (2009) use Calvo pricing framework for modeling price rigidities and use a value of 0.65 for the probability of changing prices. Barseghyan (2013) estimate for that parameter is 0.94 with an estimate of 0.32 for the indexation parameter. The prior of domestic goods stickiness parameter κ_r is set to 50. [4]

For the interest rate stickiness parameters there are no estimates for Armenia, therefore we set priors based on observed persistence of retail interest rates in Armenia.

Parameter and description		**Distribution**	**Mean**	**Std.Err**
κ_r	Domestic goods price stickiness	Gamma	50	15
κ_d^h	Home-currency deposit interest rate stickiness	Gamma	40	12
κ_d^f	Foreign-currency deposit interest rate stickiness	Gamma	50	15
$\kappa_{I,l}^h$	Home-currency loan interest rate stickiness	Gamma	60	20
$\kappa_{I,l}^f$	Foreign-currency loan interest rate stickiness	Gamma	90	30
$\kappa_{E,l}^h$	Home-currency loan interest rate stickiness	Gamma	60	20
$\kappa_{E,l}^f$	Foreign-currency loan interest rate stickiness	Gamma	90	30
κ_b^k	Bank capital cost parameter	Gamma	10	3
χ_d	Elasticity of substitution between deposit currencies	Normal	0	5
$\chi_{I,l}$	Elasticity of substitution between loan currencies	Normal	0	5
$\chi_{E,l}$	Elasticity of substitution between loan currencies	Normal	0	5

Table 2: Prior distributions of structural parameters

Some of the priors for autoregressive coefficients of shocks are set based on estimates of Barseghyan (2013). The prior for consumption preference shock and technology shock are set to 0.3 and 0.5 according to Barseghyan (2013) estimate of 0.29 and with standard deviation of 0.2. Similarly the autoregressive coefficients of UIP shock is set to 0.5 based on the same estimate of Barseghyan (2013). The autoregressive coefficients of Households and Entrepreneurs Loan-to-Value shocks are set to 0.6 to take based on observed persistence of the volume of consumer

[4]The corresponding stickiness parameters for Rotemberg pricing are assigned by the rule

$$\kappa = \frac{(\epsilon - 1)\,\theta}{(1-\theta)\,(1-\beta\theta)}$$

so that linear approximations for both cases are equivalent.

and business loans in Armenia. The autoregressive coefficients of Elasticities of substitution of goods are set to 0.3 because of observed volatility of both overall and imported goods inflation. For all other autoregressive coefficients the prior is set to 0.5 with standard deviation of 0.2.

Paramter and description		Distribution	Mean	Std.Err
AR(1) coefficients				
ρ_a	Technology shock	Beta	0.5	0.2
ρ_m^e	Entrepreneurs Loan-to-Value shock	Beta	0.6	0.2
ρ_m^h	Households Loan-to-Value shock	Beta	0.6	0.2
ρ_y	Elasticity of substitution of domestic goods shock	Beta	0.3	0.2
ρ_{UIP}	UIP shock	Beta	0.5	0.2
ρ_χ^d	Deposit dollarization shock	Beta	0.6	0.2
ρ_χ^{li}	Loan dollarization shock for Imp. households	Beta	0.6	0.2
ρ_χ^{le}	Loan dollarization shock for Entrepreneurs	Beta	0.6	0.2
ρ_B^K	Bank capital shock	Beta	0.5	0.2
$\rho_{\epsilon_{dh}}$	Home-currency deposit interest rate shock	Beta	0.5	0.2
$\rho_{\epsilon_{df}}$	Foreign-currency deposit interest rate shock	Beta	0.5	0.2
$\rho_{\epsilon_{lIh}}$	Home-currency loan interest rate for Imp	Beta	0.5	0.2
$\rho_{\epsilon_{lEf}}$	Foreign-currency loan interest rate shock for Ent	Beta	0.5	0.2
ρ_I	Investment shock	Beta	0.5	0.2
$\rho_{\epsilon_h^i}$	Monetary policy shock	Beta	0.4	0.2
ρ_g	Government consumption shock	Beta	0.4	0.2

Table 3: Prior distributions of autoreressive coefficients of shocks

4.4 Posterior estimates

Posterior estimated are obtained by Metropolis-Hastings MCMC algorithm running 5 parallel chains with 100000 draws each. The posterior estimates of structural parameters and autoregressive coefficients od shocks are presented in Table 4, and the estimates of standard errors of shocks are presented in Table 5.

The estimates of autoregressive coefficients generally are in line with priors with those of dollarization rates showing higher persistence than expected. Also estimates of Entrepreneurs loans interest rate stickiness parameters are bigger than expected, implying higher degree of rigidities in those markets.

The estimates of elasticities of substitution between Home- and Foreign-currency deposits and loans are controversial. The parameter of deposit dollarization is estimated to be 6.1. This parameter was supposed bo be negative, which would mean that consumers increase their holdings of Home-currency deposits when the return of it is expected to increase relative to return of Foreign-currency deposits and similarly increase their holdings of Foreign-currency deposits when the return of it is expected to increase relative to return of Home-currency deposits.

With a negative elasticity of substitution the households do not maximize the expected return, bu instead minimize, which means, that th currency structure of deposits in being determined in benefit of banks, rather than in benefit of households. This may be because households cannot accurately predict exchange rate movements, but banks can. Or the expectations of households are backward looking, instead of being rational and forward looking.

Parameter	**Prior**		**Posterior**		**90% HPD interval**	
	Mean	St.dev.	Mean	St.dev.	inf	sup
κ_p	50.000	15.0000	35.163	11.5078	17.2309	53.7258
κ_d^h	40.000	12.0000	45.888	10.2346	29.7340	62.5383
κ_d^f	50.000	15.0000	49.182	14.1913	26.4390	71.2701
$\kappa_{I,l}^h$	60.000	18.0000	61.822	16.6422	35.3073	87.2288
$\kappa_{I,l}^f$	90.000	30.0000	78.332	26.2176	37.6948	119.3841
$\kappa_{E,l}^h$	60.000	18.0000	58.401	15.6115	33.6810	83.0135
$\kappa_{E,l}^f$	90.000	30.0000	83.088	26.3268	42.2952	124.7652
κ_b^k	10.000	5.0000	1.643	0.7274	0.4957	2.7800
χ^d	0.000	5.0000	6.095	1.6342	3.4343	8.7684
χ_I^l	0.000	5.0000	2.578	1.2124	0.5354	4.5121
χ_E^l	0.000	5.0000	2.185	0.9082	0.6736	3.6623

Table 4: Results from Metropolis-Hastings (parameters)

Parameter	Prior		Posterior		90% HPD interval	
	Mean	St.dev.	Mean	St.dev.	inf	sup
ρ_{e_A}	0.500	0.2000	0.481	0.1692	0.1984	0.7529
ρ_{m_e}	0.500	0.2000	0.787	0.0693	0.6778	0.8987
ρ_{m_i}	0.500	0.2000	0.940	0.0295	0.8943	0.9857
$\rho_{\varepsilon_d^h}$	0.500	0.2000	0.312	0.1175	0.1151	0.5000
$\rho_{\varepsilon_d^f}$	0.500	0.2000	0.206	0.1001	0.0435	0.3582
$\rho_{\varepsilon_{I,l}^h}$	0.500	0.2000	0.234	0.1051	0.0572	0.3919
$\rho_{\varepsilon_{I,l}^f}$	0.500	0.2000	0.435	0.1199	0.2374	0.6308
$\rho_{\varepsilon_{E,l}^h}$	0.500	0.2000	0.179	0.0922	0.0273	0.3143
$\rho_{\varepsilon_{E,l}^f}$	0.500	0.2000	0.260	0.1130	0.0743	0.4369
ρ_{ε_y}	0.500	0.2000	0.112	0.0576	0.0200	0.1987
$\rho_{e_B^K}$	0.500	0.2000	0.209	0.0828	0.0711	0.3413
ρ_{UIP}	0.500	0.2000	0.556	0.0576	0.4642	0.6504
ρ_{ξ^d}	0.600	0.2000	0.933	0.0372	0.8755	0.9857
$\rho_{\xi_I^l}$	0.600	0.2000	0.902	0.0410	0.8393	0.9673
$\rho_{\xi_E^l}$	0.600	0.2000	0.807	0.0749	0.6904	0.9327
ρ_g	0.500	0.2000	0.741	0.0753	0.6247	0.8592
$\rho_{e_i^h}$	0.400	0.2000	0.114	0.0598	0.0161	0.2012

Table 5: Results from Metropolis-Hastings (AR(1) coefficients)

The elasticities of substitution between Home- and Foreign-currency loans have the expected sign and are estimated at 2.58 and 2.19 for Household and Business loans, respectively. This means, that Home- and Foreign currency loans are imperfect substitutes for Households and Entrepreneurs. This can be because households and entrepreneurs have certain preferences of loan currency. For example, firms which operate in export or import sector will seek mostly Foreign currency loans to have balanced cash flows. For these companies Home-currency loans are not perfect substitutes for Foreign-currency loans. Similarly, the households with significant share of remittance in their incomes will prefer foreign currency loans despite interest rate differentials or exchange rate movements.

Parameter	Prior		Posterior		90% HPD interval	
	Mean	St.dev.	Mean	St.dev.	inf	sup
ε_{e^A}	0.100	Inf	0.039	0.0103	0.0234	0.0550
ε_{me}	0.050	Inf	0.028	0.0056	0.0192	0.0368
ε_{mi}	0.050	Inf	0.018	0.0020	0.0150	0.0214
$\varepsilon_{\varepsilon^{dh}}$	0.100	Inf	0.474	0.1052	0.3065	0.6405
$\varepsilon_{\varepsilon^{df}}$	0.100	Inf	0.795	0.2092	0.4439	1.1172
$\varepsilon_{\varepsilon^{lih}}$	0.100	Inf	3.058	0.8836	1.6567	4.4076
$\varepsilon_{\varepsilon^{lif}}$	0.100	Inf	2.844	1.1005	1.1200	4.4829
$\varepsilon_{\varepsilon^{leh}}$	0.100	Inf	2.738	0.7420	1.5522	3.8768
$\varepsilon_{\varepsilon^{lef}}$	0.100	Inf	3.889	1.4185	1.7253	5.8430
ε_i^h	0.010	Inf	0.004	0.0004	0.0030	0.0042
ε_y	1.000	Inf	5.902	1.9729	2.7149	8.9159
$\varepsilon_{e_B^K}$	0.100	Inf	0.146	0.0154	0.1220	0.1717
ε_{ξ^d}	0.050	Inf	0.029	0.0031	0.0239	0.0340
$\varepsilon_{\xi_I^l}$	0.050	Inf	0.021	0.0024	0.0175	0.0249
$\varepsilon_{\xi_E^l}$	0.050	Inf	0.015	0.0016	0.0121	0.0172
ε_{UIP}	0.100	Inf	0.021	0.0036	0.0155	0.0269
ε_{Π^f}	0.010	Inf	0.014	0.0016	0.0119	0.0170
ε_g	0.100	Inf	0.245	0.0314	0.1941	0.2954

Table 6: Results from Metropolis-Hastings (standard deviation of structural shocks)

The results of estimation are presented in Figure 4.

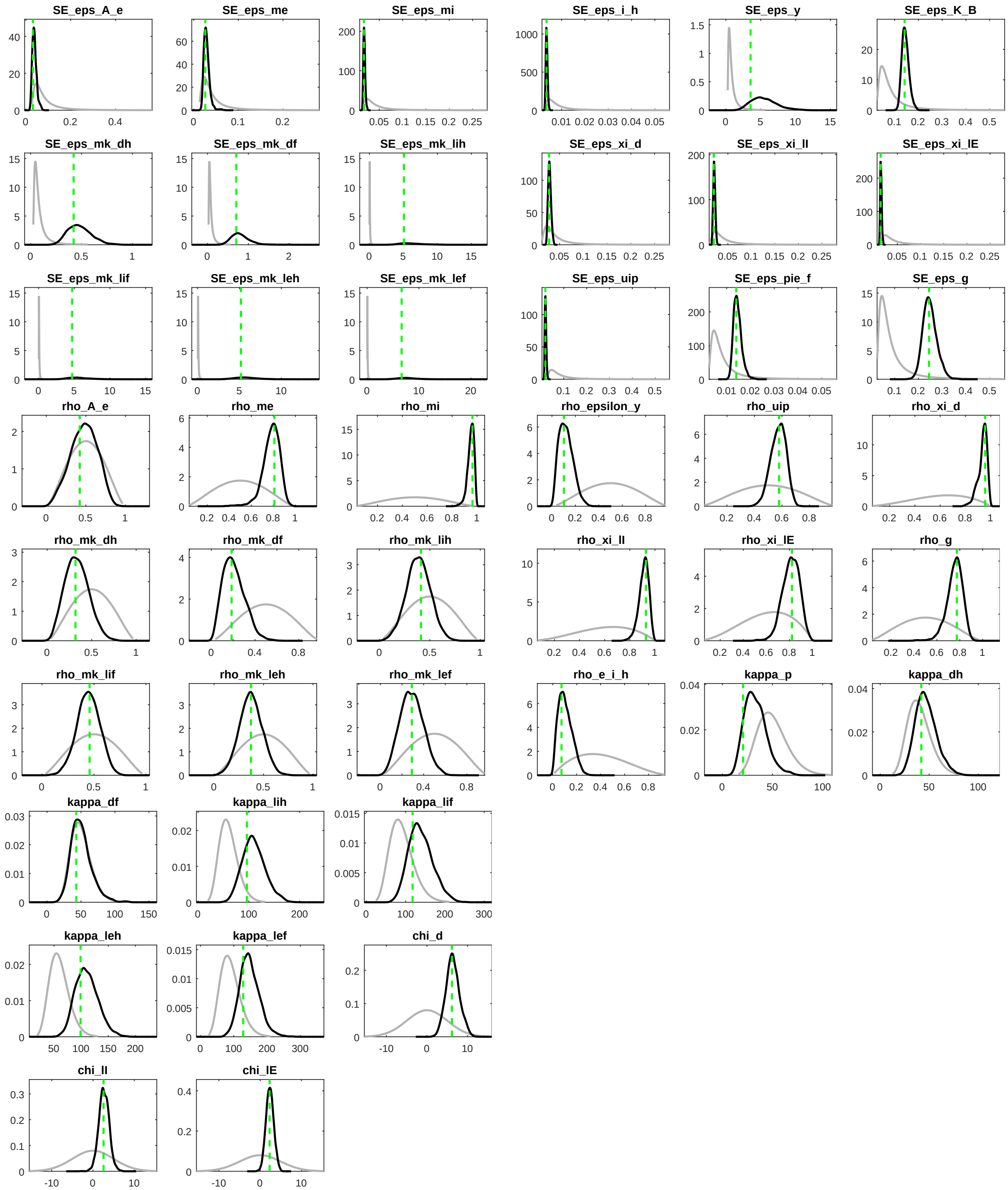

Figure 4: Prior distributions and Posterior estimates

5 Model analysis

In this section we compare the estimated with the one without dollarization. We compare the impulse response functions of Monetary policy shock, Technology shock (an internal shock) and UIP shock (an external shock) under different dollarization rates. The estimated baseline model has the dollarization rate of 0.65, and is compared to a one with no dollarization.

The effects of dollarization are evident when inspecting the impulse response functions of retail interest rates and exchange rate movements. In case of no dollarization the return on deposits and cost of loans depends on only interest rates and is determined at the time of making contracts. However, when dollarization is present, the return/cost on foreign currency deposits/loans partly depends on the interest rate, which is known at the time of making contract, and partly on exchange rate fluctuations, which are observed only at the time of repayments of deposits and loans. Impulse response functions show, that often exchange rate movements are of higher magnitude than interest income/cost, and the net return/cost is mainly determined by exchange rate fluctuations.

When there is a significant amount of dollarization in the economy, the effects of monetary policy actions are rather different from those in case of no dollarization. The conventional way of thinking about monetary policy is that the monetary authorities can alter the behavior of consumers by affecting their intertemproral decisions about consumption and saving by changing interest rates and through expectations of future policy actions. However, with dollarization, the effects of monetary policy are rather different. In this case exchange rate fluctuations caused by monetary policy actions have considerable revaluation effects on deposits and loans. This feature underlines the importance of exchange rate channel of the monetary policy in dollarized economies, as it primarily affects the wealth of consumers, rather than their decisions of consumption and saving.

5.1 Technology shock

The response of the economy to a Technology shock is presented in Figure 5. The behavior of macroeconomics variables - output inflation exchange rates - is very similar in three models. Loans and deposits show higher degree of variability in baseline model, whereas interest rates are more volatile.

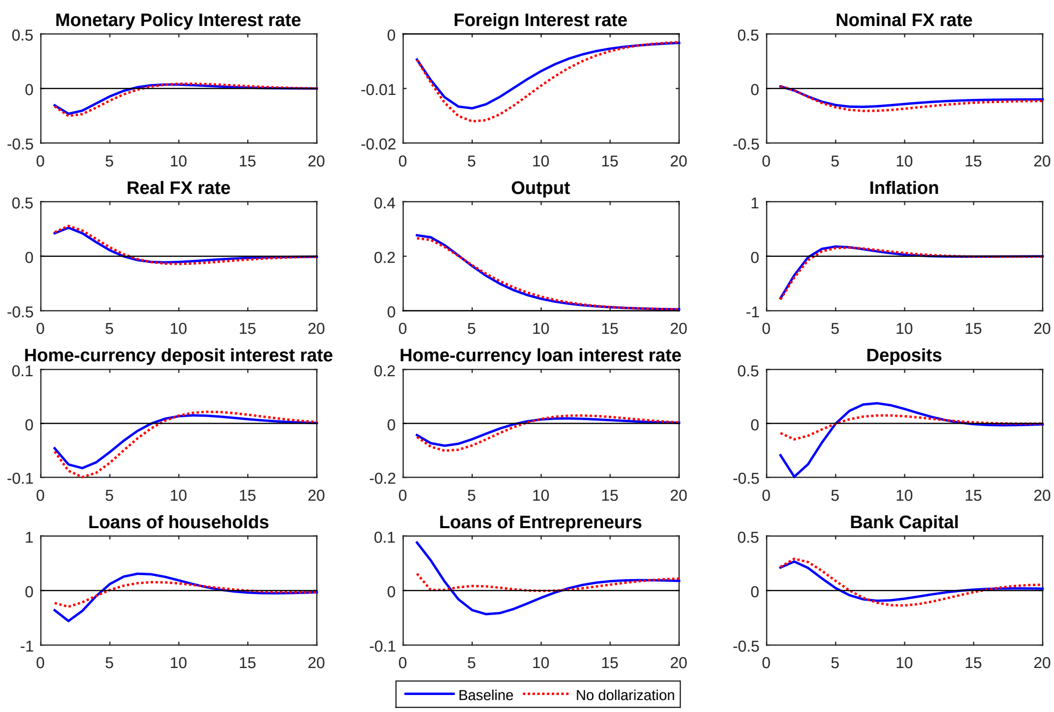

Figure 5: Technology shock

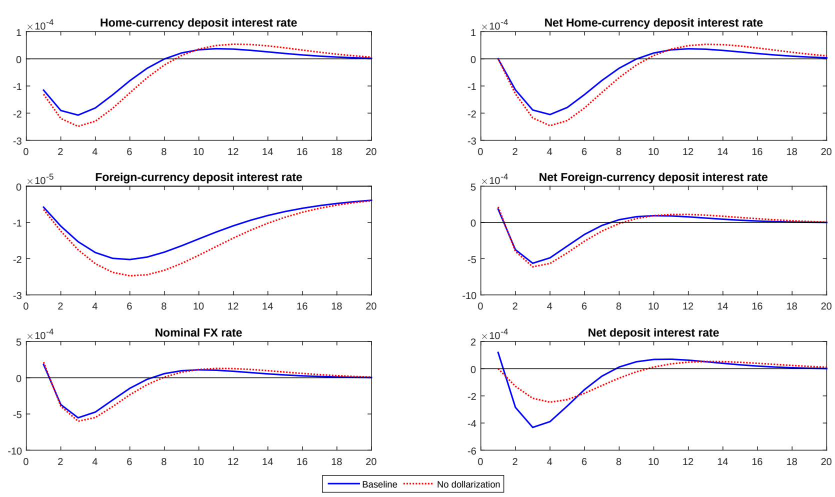

Figure 6: The response of Deposit interest rates to a Technology shock

5.2 Monetary policy shock

The effects of monetary policy shock on output are increasing as dollarization decreases. On the other hand the control over the inflation does not increase as dollarization decreases. Also interest rates are less volatile in the estimated model. The drop in loans of Entrepreneurs in bigger in the baseline model, whereas the decline in deposits and loans of households is bigger in the model with the model without dollarization.

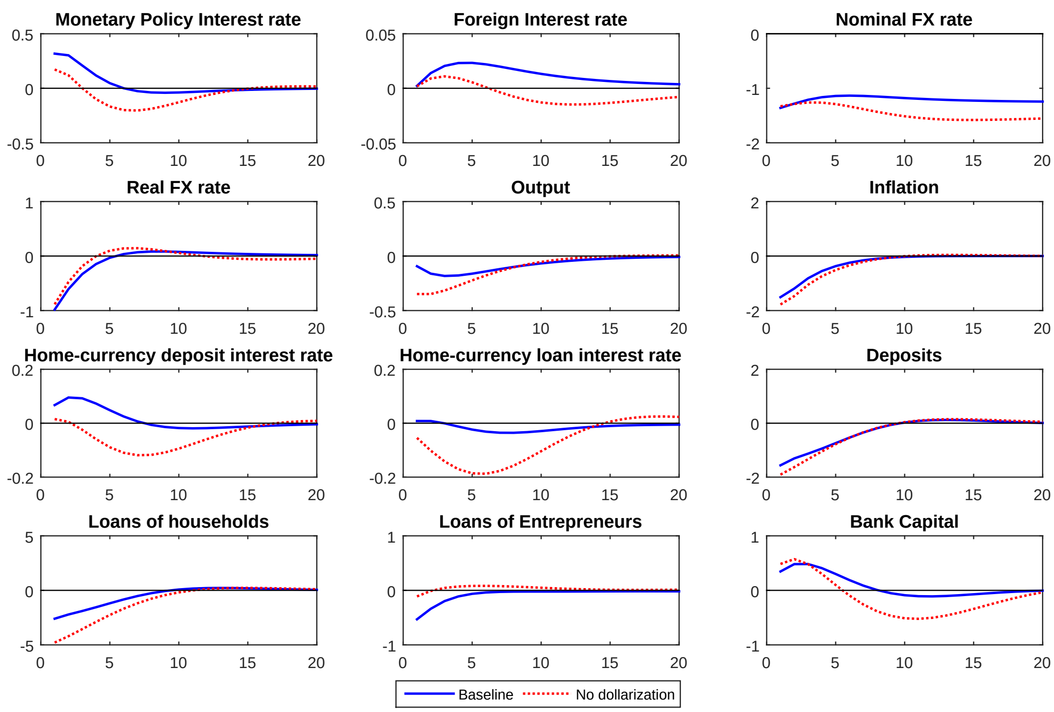

Figure 7: Monetary policy shock

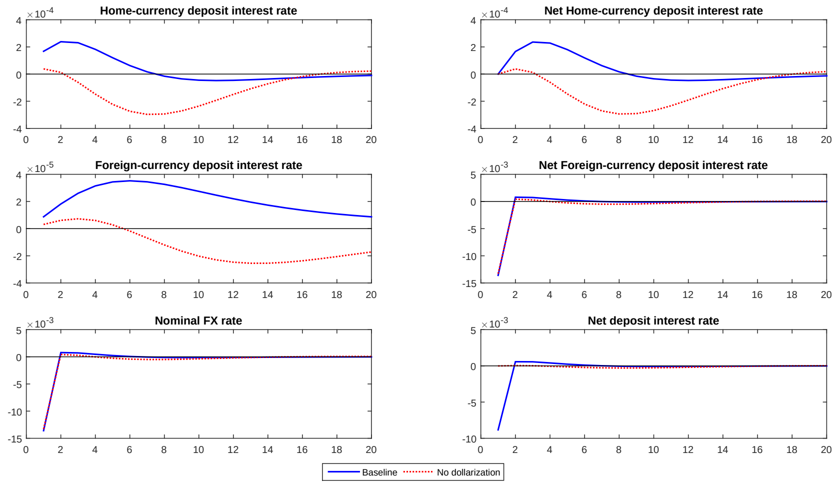

Figure 8: The response of Deposit interest rates to a Monetary policy shock

5.3 UIP shock

In case of Uncovered interest parity shock the response of the economy is smoother in the model with no dollarization. The decline in output in baseline model is relatively greater and inflation stabilization is slower than in other models. All financial system variables interest rates, deposits, loans and bank capital show high volatility in baseline model.

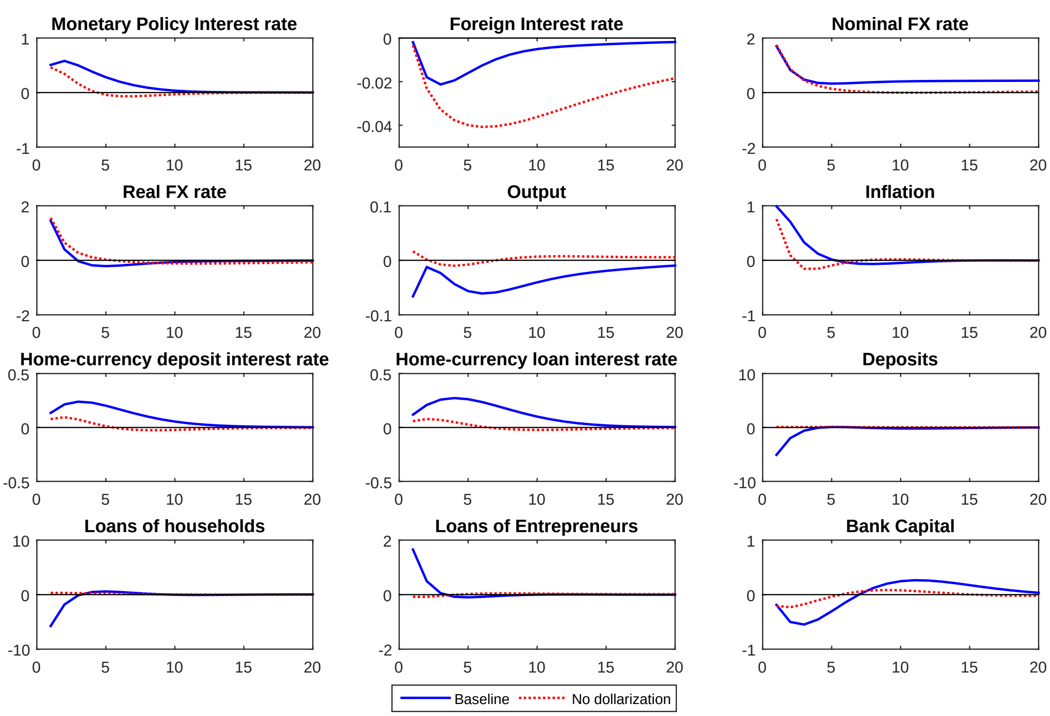

Figure 9: UIP shock

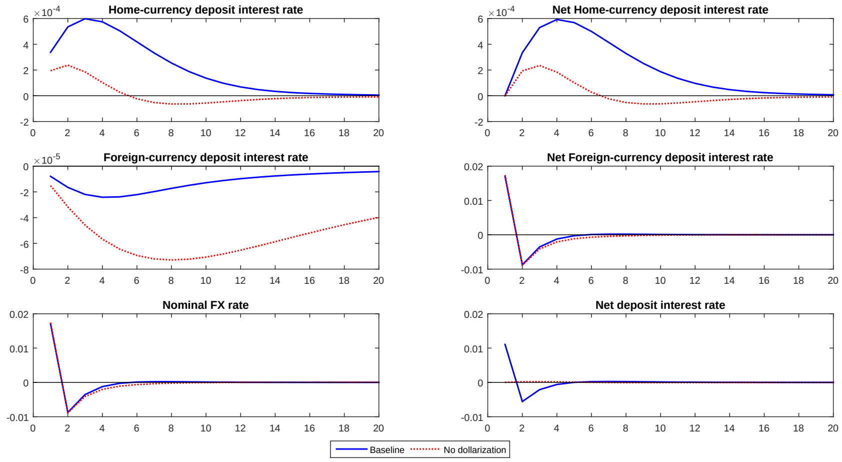

Figure 10: The response of Deposit interest rates to a UIP shock

To summarize, the effects of financial dollarization are sizable in case of monetary policy and UIP shocks and are of lower magnitude in case of technology shock. This means that under high dollarization the economy is more vulnerable to external shocks, and the whereas it is more resilient to case of internal shocks. This result is consistent with the findings of Castillo et al. (2013). Also, as expected, the interest rate channel is weaker in case of dollarization.

6 Conclusion

In the paper an open economy Dynamic Stochastic General equilibrium model with endogenous dollarization is developed. The model incorporates a portfolio allocation problem in households' and entrepreneurs' decisions, so that they choose optimal currency structure of their deposits and loans based on interest rate differentials and their expectations about exchange rate movements. The optimal structure of deposit and loan portfolios yields in disparate dollarization rates.

Banks play a key role in the model by bearing the risks of changing dollarization. The optimal structure of deposit and loan portfolios implies disparate dollarization rates that gives rise to an excess demand or supply of foreign currency at the household level which is then transmitted to the banking sector. With deposit and loan dollarization rates changing independently in both sides of their balance sheets, banks have to maintain closed FX positions by borrowing or lending in foreign interbank market. This feature provides an additional source of macroeconomic volatility due to dynamically changing dollarization via balance of payments and exchange rate fluctuations.

The model is estimated for Armenia using the data from 2004 to 2014. The estimation is done using Bayesian methods with Metropolis-Hastings MCMC algorithm. The comparison of the models with and with out dollarization shows that the role of monetary policy in quite different in dollarized economies, since it primarily affects the economic activity by exchange rate channel, rather than by interest rate channel. This result claims for a different approach to monetary policy implementation in dollarized countries.

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