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A DSGE Model with Financial Dollarization – the Case of Serbia

Mirko Djukić, Tibor Hlédik, Jiří Polanský, Ljubica Trajčev, and Jan Vlček *

Abstract

We amend a DSGE model of a small open economy by adding financial euroization in order to capture the main channels of the monetary transmission mechanism in match the Serbian data. In contrast to the standard DSGE workhorse, the model encompasses commercial banks and foreign-exchange-denominated deposits and loans. Given these features, the model is well suited to evaluating effects of the nominal exchange rate on the financial wealth and consumption of households. The model structure, including optimization problems and first-order conditions, is provided in the paper. The model properties are tested to match the stylized facts of dollarized economies. Specifically, the model is calibrated to the Serbian data, and a model-consistent multivariate filter is used to identify unobserved trends and gaps.

Abstrakt

Tato studie rozšiřuje standardní model všeobecné rovnováhy (model DSGE) malé otevřené ekonomiky o finanční eurizaci, aby lépe odrážel měnový transmisní mechanismus v srbské ekonomice. Ve srovnání se standardním modelem DSGE zahrnuje náš modelový rámec komerční banky obhospodařující vklady a poskytující úvěry v cizí měně. Tyto vlastnosti umožňují zkoumat vliv změn nominálního měnového kurzu jak na finanční bohatství domácností, tak na jejich spotřební chování. Součástí článku je modelová struktura, včetně optimalizačních problémů jednotlivých ekonomických subjektů a korespondující podmínky prvního řádu. Modelové vlastnosti byly kalibrovány tak, aby plně odrážely stylizovaná fakta pozorovaná v dolarizovaných ekonomikách. Model je kalibrován na srbská data. Nepozorované trendy a odchylky hlavních reálných modelových proměnných od těchto trendů byly odhadovány pomocí modelově konzistentního vícerozměrného filtru.

JEL Codes: E44, F41, F47.
Keywords: DSGE model, financial dollarization.

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Nontechnical Summary

This paper presents the results of a technical cooperation project between the Czech National Bank and the National Bank of Serbia (NBS) focusing on the development of a dynamic stochastic general equilibrium (DSGE) model incorporating financial euroization. The model reflects the stylized facts and macroeconomic dynamics of a small open economy experiencing euroization. In this regard, the paper responds to the growing interest in macro-financial linkages in emerging and developing market countries with financial euroization, such as Serbia. These countries modernize their policy frameworks by either moving towards inflation targeting (IT) or allowing for higher nominal exchange rate flexibility. However, due to financial euroization, the common DSGE model structure and transmission channels are not sufficient to capture the effects of exchange rate dynamics on the financial wealth of households. Similarly, DSGE workhorse models omit the financial sector, banks in particular, so they are not suitable analytical tools for evaluating the effects of macro-prudential measures.

In response to growing demand, the paper presents a structural DSGE model featuring financial euroization. The paper does not have the ambition to contribute to the theoretical literature introducing financial frictions within the endogenous money creation framework. On the contrary, the paper provides a simple approach to extending the existing DSGE workhorse model to include financial sector variables and introduce explicit banking at relatively low costs. Furthermore, the model is not designed to be a forecasting model to replace the existing QPM at the National Bank of Serbia (NBS). Rather, it should be considered an attempt to build up a model which is rich enough to analyze the macroeconomic effects of euroization in Serbia.

To introduce financial frictions, the model assumes two types of households – net borrowers and net lenders. Net borrowers have to finance part of their expenditures using loans, borrowing against their wage income. Commercial banks play the role of financial intermediaries, providing loans to households on the asset side and collecting deposits on the liability side. Financial euroization is represented by foreign exchange (FX) denominated deposits and loans on commercial bank balance sheets. The share of FX loans and deposits is assumed to stay constant, given the insurance motivation of financial euroization in Serbia.

Banks are subject to regulatory requirements in the model. The requirements consist of capital requirements, approximated by the loan-to-deposit ratio. A penalty is applied to banks whenever they deviate from the loan-to-deposit ratio set by the central bank. Apart from the financial block, the structure of the model is consistent with the common DSGE workhorse for a small open economy. The paper provides a detailed description of the optimization problems of economic agents and the corresponding first-order conditions.

The model is calibrated to match the actual data of Serbia. Serbia is characterized by euroization at about 70 percent of total deposits and loans. Unlike banks, households and firms are not hedged against currency risks. As their revenues are mainly in dinars and most of their liabilities are in FX-indexed instruments, their financial position and wealth are affected by exchange rate dynamics. Given that households are net borrowers, there are sizable negative effects of FX depreciation on private consumption.

The model properties are presented in the paper and discussed with regard to the stylized facts about Serbia. Specifically, an unexpected depreciation, an increase of the country risk premium, and a hike of the central bank rate are reported and described using the model transmission mechanism. The paper concludes with filtration of historical data for Serbia. As the core of the model is derived in stationary form, trends are exogenous to the model. This allows us to match the observed data without de-trending them.

1. Introduction

The main goal of this paper is to present the results of a technical cooperation project between the Czech National Bank and the National Bank of Serbia (NBS) focusing on the development of a dynamic stochastic general equilibrium (DSGE) model incorporating financial euroization. The model was developed to serve as a complementary analytical tool in the NBS's Monetary Analyses and Statistics Department. It extends the suit of models used for policy analysis at the Bank, enabling the quantification of the impact of financial euroization on the Serbian economy. Some of the modeling choices (constant steady-state shares of financial euroization, exogenous exports, etc.) reflect the preference of the authors to keep the model tractable. Tractability was a high priority in order to be able to bring the model to the data and operationalize policy work at a later stage. The paper is therefore expected to inspire economists working at policy-making institutions in countries with a high level of euroization (dollarization) and searching for tractable policy analysis tools.

The importance of dynamic stochastic general equilibrium (DSGE) models in central banks has been growing in recent years. In fact, most central banks in both developed and emerging market countries have introduced DSGE models as a core forecasting tool within their FPAS,[1] while some of them are still in the implementation process. The use of such models for monetary policy (MP) purposes is mainly a response to the need for deeper and internally consistent macroeconomic analysis in line with recent advancements in the macroeconomic forecasting field (Christiano et al., 2005; Smets and Wouters, 2003, 2007). Although central bank staff can generate efficient forecasts with QPM-style macroeconomic models,[2] a full-fledged DSGE framework offers mechanisms for answering more detailed policy questions, identifying initial conditions, and analyzing structural shocks due to its theoretical foundations and consistent structure (national accounts, relative prices, etc.).[3] Following the experience of other central banks, the NBS initiated a project, realized with technical assistance from the Czech National Bank, to introduce a DSGE model for the Serbian economy.

The inflation targeting (IT) regime was introduced at the NBS at the end of 2008. The inflation target is defined in terms of headline inflation. The main forecasting tool in the IT process is the QPM, a New Keynesian gap type of model, described in Djukić et al. (2011). Since the introduction of the IT regime, the model has been used as a key analytical tool for generating inflation forecasts and quantifying appropriate monetary policy responses. The QPM has proved to be a useful tool for facilitating communication between the staff and the monetary policy decision makers, as well as for producing and explaining inflation forecasts to the general public. Although the QPM has shown good forecasting performance over the past years, it lacks some important features of the Serbian economy, especially ones related to monetary policy transmission in a euroized economy and the channels through which the domestic economy is affected by the ECB's monetary policy decisions.

As a further step aimed at developing alternative models for analyzing country-specific features of the Serbian economy, the DSGE model presented in this paper includes financial euroization, reflecting the large share of loans and deposits denominated in euros, which has a significant impact on the monetary policy transmission mechanism. Including the euroized part of the financial system in the model has also enabled us to incorporate a required reserve ratio (RRR) for banks' FX liabilities.

[1] Forecasting and policy analysis system (Berg et al., 2006)
[2] Quarterly Projection Model (Berg et al., 2006)
[3] See, for example, the discussion in Bruha et al. (2013).

DSGE models have strong theoretical micro foundations. This is generally viewed as their main advantage over reduced-form gap models. They are derived based on an assumption that representative households, firms, and banks optimize their behavior in order to maximize utility and profits. Adding extra features to a DSGE model usually dramatically increases its size. Given that the paper tries to find a balance between including new features in the model and ensuring tractability, it focuses primarily on euroization and financial intermediation. As a result, we do not introduce capital and investment into our model and we capture fiscal policy in a very stylized form.

Regarding its role in policy making at the NBS, the DSGE model is to be used mainly as a policy analysis tool rather than for forecasting, which is still done by the QPM model due to its satisfactory performance. The main objective of developing the DSGE model is to contribute to the decision-making process in the NBS by deepening its analyses of the monetary policy transmission mechanism and the financial system. The new model enables us to analyze new features of the transmission mechanism not captured by the QPM model and provides a more sound framework from the theoretical perspective.

In this paper we present the structure of the DSGE model for the Serbian economy. It is a medium-scale DSGE model based on the framework of Roger and Vlcek (2011). The model embodies the main principles under which the IT regime works, i.e., a monetary policy rule keeping inflation on target. Furthermore, it contains several standard features of New Keynesian DSGE models (e.g., rational expectations and price rigidity) and it also incorporates some "non-standard" features important for emerging market economies, such as euroization. Euroization is accomplished through the introduction of an explicit banking sector into the model.

The model is calibrated taking into account recent data and specific features of the Serbian economy. This is a natural choice since the Serbian data are characterized by many underlying problems, such as a lack of long time series and frequent structural changes.

The paper is structured as follows. After presenting the literature survey, which covers DSGE models, we turn to presenting the stylized facts about the Serbian economy in Section 2. This is followed by in-depth analysis of the model structure in Section 3, which discusses agents' optimization problems and the first-order conditions. Parameter identification and the model's features as given by its impulse response functions are described in Section 4. Section 5 concludes.

1.1 General Overview of DSGE Models with Dollarization

From the 1970s onwards, many researchers strove to enhance the features of the neo-Keynesian models which were prevalent at that time. Research focused on the development of new macroeconomic models derived from microeconomic foundations and based on rational expectations to address the Lucas critique. As a result of those endeavors, DSGE models appeared to be able to successfully account for most of the research demands at the time.

Having in mind that Serbia is a highly euroized economy, we put a special emphasis on the literature covering this topic. Euroization/dollarization can be official (*de jure*), when foreign currency is legally used in parallel to, or instead of, the domestic currency, or unofficial (*de facto*), i.e., the partial use of foreign currency by domestic agents when it is not a legal tender. There are three main types of unofficial dollarization recognized in the literature: transaction dollarization (or currency substitution, when foreign currency is used as a medium of exchange), price dollarization (when prices are indexed to changes in the exchange rate), and financial dollarization (when foreign currency is used as a store of value).[4]

Here, we deal with financial dollarization, which means that there is a non-zero share of foreign currency assets and liabilities in the financial system. The term dollarized stems from the fact that most of the countries dealing with this issue come from Latin America, where the dollar is used as a means of payment and a store of value in parallel with the national currency. Today, this problem is also recognized in Central and Eastern European countries, where foreign-currency, mostly euro, denominated assets and liabilities make up a significant part of residents' financial portfolios. So, we can talk about euroization in the case of Serbia, and we use euroization and dollarization interchangeably in the paper.

Most of the literature focuses on transaction and price dollarization, but we are solely interested in financial dollarization. Yeyati (2006) gives a good overview of the implications of financial dollarization for the transmission mechanism and monetary policy. He explains that models that try to capture financial dollarization usually do this through three different channels: 1) the portfolio view, which sees financial dollarization as the optimal choice for a given distribution of real returns in each currency in order to minimize the variance portfolio returns; 2) the market failure view, where financial dollarization is seen as a response to market imperfections, meaning that the default risk of a borrower indebted in the local currency at a high interest rate exceeds the risk of borrowing in foreign currency, as the local currency collapse risk is low; 3) the institutional view, which emphases how institutional failures can foster financial dollarization, i.e., if the government does not commit to low inflation, expectations that the government will inflate away the debt burden lead to high domestic interest rates and inflation bias. Debt dollarization can therefore be seen as an option for averting inflation bias. Yeyati (2006) shows that financially dollarized economies tend to face a higher inflation rate, a greater propensity to suffer systemic banking crises, and slower and more volatile output growth.

The recent financial crises brought to the fore the importance of financial frictions and their impact on the real economy. Since then, numerous research papers have striven to incorporate them into macroeconomic models. One can generally distinguish three approaches: 1) the financial accelerator mechanism, which is based on information asymmetry between borrowers and lenders; 2) models with collateral constraints in which loans are secured by borrowers' disposable collateral; 3) the introduction of banks explicitly into the model, usually with an assumption that banks face operating costs or regulatory requirements.

Our paper introduces a simple banking sector into the DSGE workhorse model to capture the effects of financial dollarization. Ize and Parrado (2006) investigate the causes of real and financial dollarization in the context of a small open economy model. They find that financial dollarization rises in the presence of volatility of domestic inflation and recedes during episodes of exchange rate volatility. Another example of this strand of the literature is Rennhack and Nozaki (2006), who find that financial dollarization is a rational response to increased macroeconomic uncertainty related to high inflation and exchange rate variability.

Urošević and Grga (2014) developed a DSGE model with financial euroization for the Serbian economy. They showed that due to high euroization the reference rate has a limited impact on real economic activity, since a significant part of credit is provided in foreign currency. Conversely, exchange rate dynamics matter due to a strong link between the exchange rate and default risks.

[4] Castillo et al. (2006)

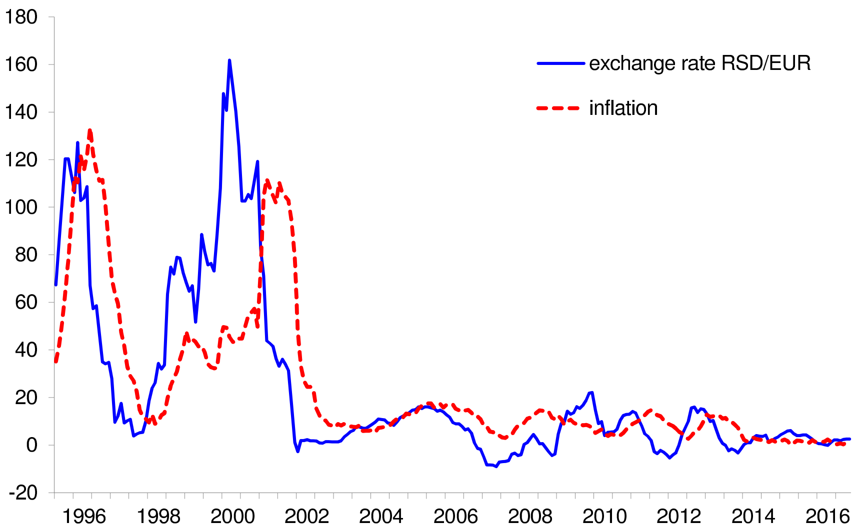
They also claim that commercial banks are less sensitive to the liquidity supplied by the central bank, as they can use funding in foreign currency. The central bank in Urošević and Grga (2014) is modeled as a partial liquidity provider and there is no active monetary policy. On the contrary, the model presented here assumes a central bank operating under the inflation targeting framework.

Copaciu et al. (2015) developed a DSGE model for the Romanian economy with financial dollarization. They distinguished two types of entrepreneurs according to the currency in which they borrow, and two types of banks to match with the entrepreneurs. In their model, banks are perfectly competitive, so the model neglects lags in the transmission of monetary policy.

2. Stylized Facts about the Serbian Economy – Support for the Implementation of the Model

The high level of euroization in Serbia is a persistent problem whose sources date back decades. After a recessionary and inflationary 1980s, the crises culminated at the beginning of the 1990s with war in the former Yugoslavia and economic sanctions against Serbia. Economic activity collapsed during this period, while fiscal dominance over monetary policy resulted in one of the highest rates of hyperinflation ever recorded, peaking in late 1993 and early 1994. Simultaneously, the banking system collapsed and, as a consequence, households' savings disappeared. This led to a protracted crisis of confidence in the banking system, with savings being kept "under the mattresses" rather than in banks. During this period, the Deutsche mark replaced the dinar almost completely, taking over the functions of money.

Figure 1: Inflation and Exchange Rate (y-o-y, in %)

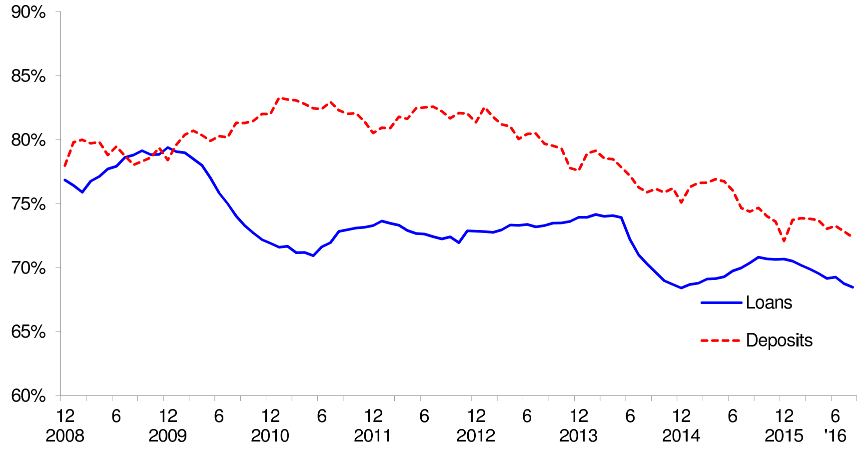


After a monetary reform in 1994, inflation was temporarily brought down into single figures, but the fiscal dominance continued, leading again to high double-digit inflation, sometimes exceeding even 100%. Although confidence in the banking system was restored during the 2000s (savings were above EUR 8 billion in 2013) and inflation was brought down to tolerable levels (8–10% on average), euroization remained very high.

Transaction and price euroization are no longer present in Serbia. Almost all transactions are made in local currency and, although the pass-through is still relatively high (0.15 in the short run), most prices are not directly FX-indexed (with few exceptions, such as prices of real estate, cars, and package holidays).

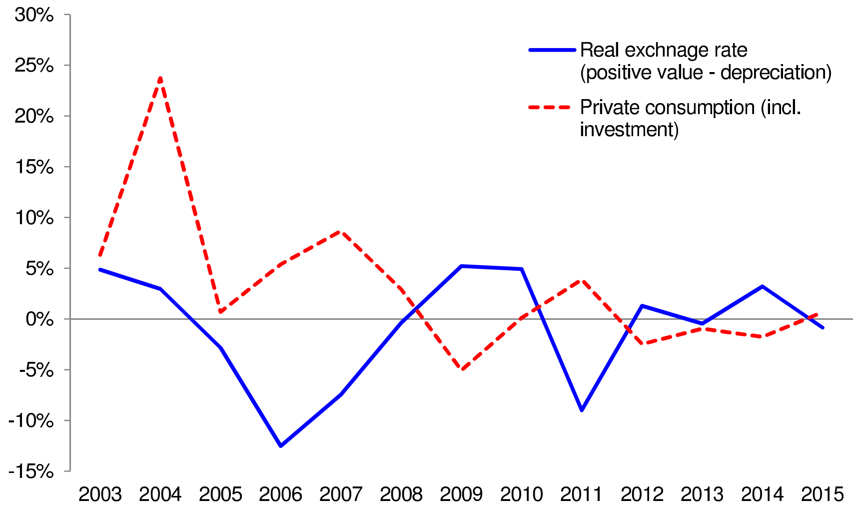
However, financial euroization is still very high. In 2016, 85% of household savings and 73% of total savings were held in foreign currencies (mostly euro) despite a high spread between dinar and euro interest rates. An additional source of euroization is foreign ownership of commercial banks, which draw FX funds from abroad (typically by borrowing from their parent banks). Having liabilities in FX (FX savings and FX borrowing), banks extend most of their loans (70%) in FX-indexed instruments. The euroization ratios (the share of FX savings and the share of FX loans) have been stable over the past decade (Figure 2).

Figure 2: Share of Indexed and FX Receivables and Payables in Total Bank Receivables and Payables from Households and Enterprises (in percent)



Unlike banks, firm and household borrowers are not hedged against the risk of dinar depreciation. As most of their revenues are in dinars and most of their liabilities to banks are in FX-indexed terms, their financial position is affected by exchange rate fluctuations. This means that depreciation of the dinar has a negative effect on domestic demand, as firms and households, both net borrowers, face higher interest payments (expressed in local currency), leaving them with less resources for consuming and investing. Figure 3 illustrates the negative correlation between real exchange rate depreciation and consumption growth in Serbia. When the negative effect of a depreciation on domestic demand is stronger than its positive effect on net exports, economic activity will fall as a result. Such depreciation also raises the ratio of foreign (FX) debt to GDP (80% in 2015). This is especially a problem for the (unhedged) government, which has two thirds of its debt denominated in foreign currencies.

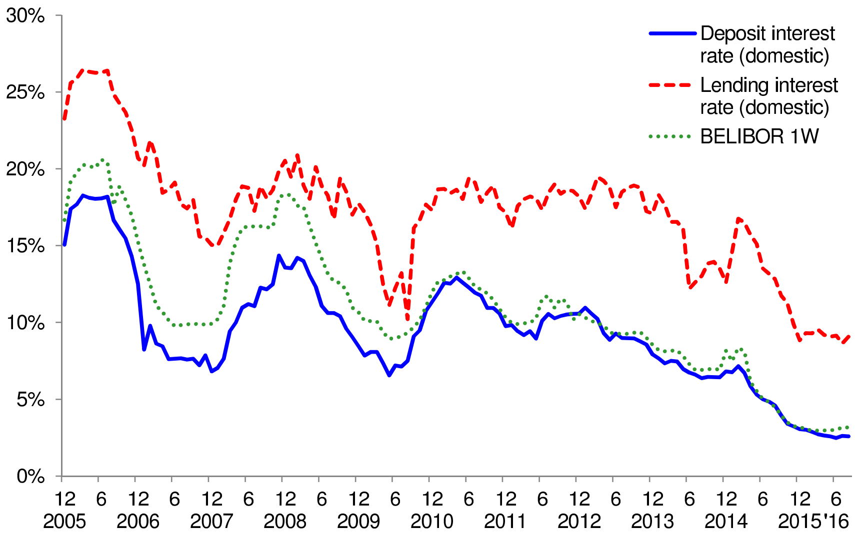
Figure 3: Real Exchange Rate Depreciation and Private Consumption + Investment Growth (in percent)



When conducting monetary and exchange rate policy, the central bank therefore has to take into account its effects on financial stability along with the primary objective of price stability. Another obvious challenge for monetary policy in a euroized economy is a weak interest rate channel.

Although there is a strong pass-through from the NBS policy rate to RSD interest rates, as shown in Figure 4, interest rates on FX loans (70%) and deposits (73%) are not affected by the NBS's policy rate. These interest rates are driven by monetary conditions in the Eurozone and the country risk premium of Serbia (which also depends on global risk aversion).

Figure 4: Interest Rates on RSD Loans and Deposits (in percent p.a.)



Reducing the level of euroization was one of the reasons why the NBS introduced inflation targeting (IT) at the end of 2008. The inflation target was set at $10 \pm 2\%$ with a gradual linear decline to $4 \pm 1.5\%$ from the end of 2012 onward. The main instrument of monetary policy is the one-week repo rate, which propagates through various transmission channels, the exchange rate channel being the strongest and fastest.

As a large part of the economy is euroized, the required reserves ratio (RRR) is also used as a monetary policy instrument, mainly in order to affect FX and FX-indexed loans. As part of the de-euroization strategy, FX liabilities are subject to a much higher RRR (13–20% depending on maturity) than dinar liabilities (0–5%). This instrument has also a financial stability purpose, as it makes savings safer, though at the cost of higher interest rates on loans. In addition, banks are required to hold a certain proportion of FX required reserves in dinars (currently 30–38% depending on the maturity of the funding sources). The main rationale for using this instrument is twofold. First, it affects exchange rate dynamics through its cash-flow effects. Second, it also influences interest rates on FX loans through different opportunity costs of holding reserves in dinars versus euros.

Finally, the NBS uses direct interventions in the foreign exchange market to smooth the volatility of the exchange rate. As a result, the FX policy of the NBS can be defined as a managed float regime. This instrument, however, is used only to reduce the short-term volatility of the exchange rate, not to influence the FX trend.

Following the introduction of the IT regime, the main challenges for monetary policy were high volatility of food prices and depreciation pressures arising mainly as a consequence of the global financial crisis. Because of food-price and risk-premium shocks, inflation in this period was very volatile and, on average, above the target. Only since late 2013 has the NBS managed to stabilize inflation at a relatively low level, around 1–2%.

Serbia is a small open economy exposed to external shocks. In the pre-crisis period, growth was driven mostly by rising domestic demand, leading to unsustainable external imbalances. After the collapse of Lehman Brothers, net exports improved considerably in Serbia, mainly as a result of a significant fall in import demand caused by a drop in domestic demand. At the same time exports improved as well, as the dinar depreciated significantly in the first months of the crisis. By 2009, the current account deficit had fallen to less than a third of the 2008 level. As of 2016, exports are 70% above the pre-crisis level, while imports are 13% above. Nevertheless, the ratio of imports to GDP (57.4%) is still much higher than that of exports (47.7%).

3. Structure of the Model

3.1 Model Overview

The model is based on the framework of Roger and Vlcek (2011). It has been extended to incorporate several features which are not embedded in the original model. These mainly include euroization and a set of equations for model-consistent filtering of gaps. The original model is developed to match the stylized facts of emerging market economies. Besides several widely used features of DSGE models (e.g., real and nominal rigidities), it contains an explicit banking sector allowing the credit channel and the share of dollarization in the economy to be captured.

Since the motivation for using DSGE models and their features are widely described in the literature, we focus mainly on briefly describing the model and its equations.[5]

The model contains two types of households (savers and borrowers),[6] intermediate-goods-producing firms, final-goods-producing firms, a labor bundle, exporters, retail banks, wholesale banks, and monetary and fiscal authorities.[7] Households consume final consumption goods, save deposits at, or take loans from, commercial banks, and supply labor. Intermediate firms use labor and imports to produce intermediate goods. An assumption that firms finance a constant share of their production through commercial banks' loans is used to motivate demand for loans from firms. Monopolistically competitive retailers use intermediate goods to produce final goods, facing a Calvo signal to change their prices. Final goods are consumed by households and the government. Exporters are assumed to be independent of the domestic intermediate sector and face exogenous terms of trade.

Commercial banks collect deposits from households and borrow from abroad on the liability side while extending loans on the asset side. Deposits and foreign liabilities are assumed to be perfect substitutes. Banks also have to maintain a minimum loan-to-deposit ratio.[8] If they deviate below this ratio, they face penalty charges. The monetary authority targets year-on-year inflation four periods ahead via an interest rate rule. The government finances its spending by issuing government bonds and collecting lump-sum taxes. The ratio of nominal government spending to nominal private consumption is assumed to be constant in the long run.

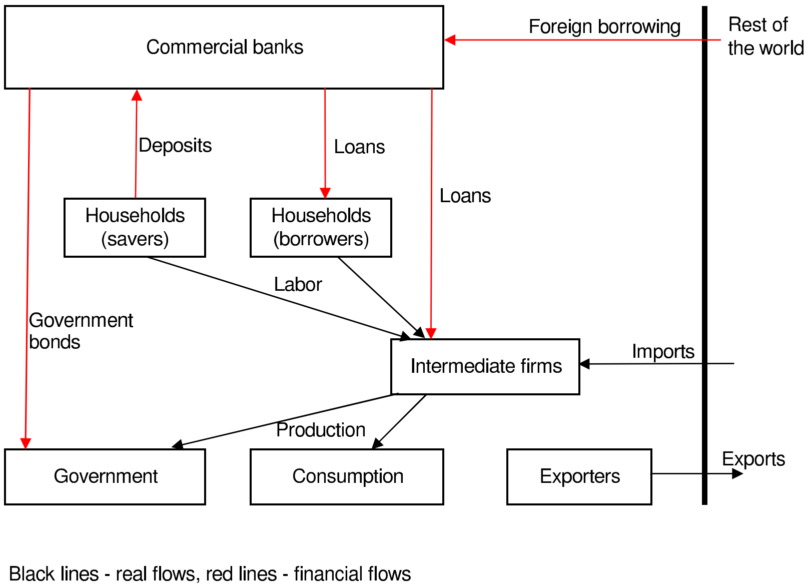
The model captures the interaction between real and nominal financial variables in a consistent way. The structure of the model is presented in Figure 5.

3.2 Households

Households in the model are divided into (net) savers and (net) borrowers. This distinction is particularly important in dollarized economies, as the wealth effects of nominal depreciation of the local currency are positive for savers and negative for borrowers. Furthermore, the reaction of borrowers to a depreciation is typically more pronounced, because they immediately suffer from higher monthly interest payments, which leaves their disposable income lower. FX savers are expected to react more slowly to their higher income (expressed in domestic currency). We address this fact by calibrating different habit coefficients for the two groups (which will be described in

[5] This section discusses the optimization problems and equations of the non-linear model version.
[6] Similar to the Gerali et al. (2010) framework with patient and impatient households.
[7] Final goods producers, wholesale banks, and the labor bundle are introduced for technical reasons to simplify the optimization problem.
[8] One can think of this ratio as a regulatory requirement set implicitly by the policy authority by imposing restrictions on the capital adequacy ratio.

Figure 5: Structure of the Model



Section 4.1). Households do not optimize with respect to the level of euroization, as it represents insurance against macroeconomic volatility rather than search for yield.

In the basic setting, the only difference between the two groups is that savers receive revenues from their deposits, whereas borrowers pay interest on loans in the budget constraint.

There is a continuum of households indexed on a unit interval i. Households maximize their utility function separable in its two arguments (consumption and leisure). The utility function contains external habit formation Abel (1990) and does not contain real money balances (due to full endogeneity of money). The maximization problem has the form:

$$\max_{C_t^h(i),N_t^h(i)} E_t \sum_{t=0}^{\infty} \beta^t \; [(1-\chi^h)\log(C_t^h(i) - \chi^h \bar{C^h}_{t-1}) - N_t^h(i)], \tag{1}$$

where $h = \{s, b\}$ in the superscript refers to net savers or net borrowers. C_t^h denotes (real) consumption, $\bar{C^h}_{t-1}$ is the past aggregate consumption of each group of households, N_t^h is the labor effort (hours worked), β is the discount factor, and χ^h is the habit persistence smoothing parameter. The share of net saver households is γ^s.

3.2.1 Net Savers

Net saver households consume final consumption goods, supply labor, and save deposits denominated in domestic and foreign currency at commercial banks. Their income comprises labor income, revenues from deposits, lump-sum net payments from the government, and dividends from ownership of firms and banks.

The previously mentioned maximization problem is set given the budget constraint:

$$P_tC_t^s(i) + D_t^d(i) + S_tD_t^f(i) \leq W_t^sN_t^s(i) + (1+i_{t-1}^{dd})D_{t-1}^d(i) + (1+i_{t-1}^{df})S_tD_{t-1}^f(i) + \gamma^s\Gamma_t + \Pi_t, \quad (2)$$

where P_t is the price level,[9] D_t^d are deposits in the domestic currency, D_t^f are deposits in the foreign currency, S_t denotes the nominal exchange rate, W_t^s is the nominal wage, i_t^{dd} is the nominal interest rate on deposits in the domestic currency, i_t^{df} is the nominal interest rate on deposits in the foreign currency, $\gamma^s\Gamma_t$ denotes lump-sum net payments from the government that go to net savers, and Π_t are dividends (profits).

Financial dollarization is introduced through the assumption that households can save deposits denominated in both the home and foreign currencies at commercial banks. The share of foreign currency deposits in total deposits is exogenous and equal to parameter $\lambda \in [0,1]$, where a higher parameter value implies a higher share of dollarization. Thus, the use of a constant nominal share of foreign and domestic currency deposits implies a slightly modified optimization problem of households

$$\max_{C_t^s(i),D_t(i),N_t(i)} E_t \sum_{t=0}^{\infty} \beta^t \{ [(1-\chi^s)\log(C_t^s(i) - \chi^s\bar{C^s}_{t-1}) - N_t^s(i)] \quad (3)$$
$$- \Lambda_t^s[P_tC_t^s(i) + D_t(i) - W_t^sN_t^s(i) - (1+i_{t-1}^{dd})(1-\lambda)D_{t-1}(i) - (1+i_{t-1}^{df})\dot{S}_t\lambda D_{t-1}(i) - \gamma^s\Gamma_t - \Pi_t]\},$$

where D_t denotes total deposits and $\dot{S}_t = \frac{S_t}{S_{t-1}}$ is the gross rate of nominal exchange rate change, where $\dot{S}_t > 1$ refers to depreciation and $\dot{S}_t < 1$ to appreciation. Λ_t^s denotes the shadow price of wealth.

Assuming flexible wages, the solution to the above-mentioned optimization problem results in the following equations:[10]

$$\frac{1-\chi^s}{C_t^s - \chi^s C_{t-1}^s} = \Lambda_t^s P_t, \quad (4)$$

$$\Lambda_t^s = \beta\Lambda_{t+1}^s[(1-\lambda)(1+i_t^{dd}) + \lambda(1+i_t^{df})\dot{S}_{t+1}], \quad (5)$$

$$\Lambda_t^s W_t^s = 1. \quad (6)$$

The first- order condition with respect to labor (6) can be substituted into the other two to eliminate the shadow price of wealth Λ_t^s. The optimality conditions have the form

$$\frac{C_t^s - \chi^s C_{t-1}^s}{1-\chi^s} = \frac{W_t^s}{P_t}, \quad (7)$$

$$\frac{C_{t+1}^s - \chi^s C_t^s}{C_t^s - \chi^s C_{t-1}^s} = \beta[(1-\lambda)(1+i_t^{dd}) + \lambda(1+i_t^{df})\dot{S}_{t+1}]\frac{1}{\dot{P}_{t+1}}, \quad (8)$$

[9] For simplicity, we do not distinguish between the price level and the consumption price deflator.
[10] Symmetric equilibrium is assumed after deriving the first-order conditions, e.g., $\bar{C^s}_t = C_t^s(i) = C_t^s$. Thus, none of the optimality equations in the paper contains indices for the continuum of households, firms, or banks, or "bars" for aggregate variables.

where $\dot{P}_{t+1} = \frac{P_{t+1}}{P_t}$ is the expected gross inflation rate. The first equation equalizes the real wage and the marginal rate of substitution between consumption and leisure. The second equation is a modified version of the Euler equation balancing current and future discounted marginal utilities from consumption. Within the model, the two interest rate yields, i.e., $(1+i^{dd})$ and $(1+i^{df})\dot{S}$, are equal in the steady state, but can deviate from each other along business cycles.

3.2.2 Net Borrowers

On the other side there is a fraction of households which are net borrowers. Their objective is similar to that of savers, but with the difference that they can boost their consumption by borrowing from commercial banks. Thus, their budget constraint is:

$$P_t C_t^b(i) + (1+i_{t-1}^{ld})L_{t-1}^{hd}(i) + (1+i_{t-1}^{lf})S_t L_{t-1}^{hf}(i) \leq W_t^b N_t^b(i) + L_t^{hd}(i) + S_t L_t^{hf}(i) + (1-\gamma^s)\Gamma_t, \tag{9}$$

where L_t^{hd} and L_t^{hf} refer to loans to households granted by commercial banks in domestic and foreign currency, respectively. The share of foreign currency loans in total loans (L_t^h) is exogenous and equal to parameter λ, the same as for deposits held by savers. Every period, borrowers repay all their loans at the previously negotiated nominal rate for domestic (i_{t-1}^{ld}) and foreign (i_{t-1}^{lf}) currency loans and take out new ones. Thus, their income comprises labor income, new loans, and lump-sum transfers.

We introduced a borrowing constraint similar to the debt-to-income ratio which is approximated by

$$L_t^h \leq m W_t^b N_t^b. \tag{10}$$

This means that the loan amount that households borrow is proportional to their wage.[11] Substituting (10) in the budget constraint eliminates loans from the maximization problem, which now has the following form

$$\begin{aligned}\max_{C_t^b(i), N_t^b(i)} E_t \sum_{t=0}^{\infty} \beta^t \{ \; & [(1-\chi^b)\log(C_t^b(i) - \chi^b \bar{C^b}_{t-1}) - N_t^b(i)] \\ & - \Lambda_t^b [P_t C_t^b(i) + (1+i_{t-1}^{ld})(1-\lambda) m W_{t-1}^b(i) N_{t-1}^b(i) + (1+i_{t-1}^{lf})\dot{S}_t \lambda m W_{t-1}^b(i) N_{t-1}^b(i) \\ & - W_t^b N_t^b(i)(1+m) - (1-\gamma^s)\Gamma_t]\},\end{aligned} \tag{11}$$

where Λ_t^b stands for the borrowers' shadow price of wealth, and m is the fraction of the wage up to which loans can be extended.

Solving the maximization problem results in the following equations:

$$\frac{1-\chi^b}{C_t^b - \chi^b C_{t-1}^b} = \Lambda_t^b P_t, \tag{12}$$

$$\frac{\Lambda_t^b}{\Lambda_{t+1}^b} = \frac{1}{\Lambda_{t+1}^b W_t^b (1+m)} + \beta W_t^b m[(1-\lambda)(1+i_t^{ld}) + \lambda(1+i_t^{lf})\dot{S}_{t+1}]. \tag{13}$$

[11] In Iacoviello (2005) collateral constraints are tied to housing value, but Serbian banks have a regulatory rule that the monthly installment cannot exceed a certain fraction of the client's wage.

Equalizing the marginal rate of consumption and labor we get a relationship between consumption, the real interest rate, and the real wage.

$$\frac{C^b_{t+1}-\chi^b C^b_t}{C^b_t-\chi^b C^b_{t-1}} = \beta W^b_t m[(1-\lambda)(1+i^{ld}_t)+\lambda(1+i^{lf}_t)\dot{S}_{t+1}]\frac{1}{\dot{P}_{t+1}} + \frac{1}{1+m}\frac{P_t}{W^b_t}\frac{C^b_{t+1}-\chi^b C^b_t}{1-\chi^b}. \tag{14}$$

From (14) we can see a positive relationship between future consumption and the loan-to-income ratio (m).

3.3 Production

3.3.1 Intermediate Producers

The competitive domestic intermediate goods producers combine households' labor and imported goods through Cobb-Douglas constant-returns-to-scale technology. They produce the intermediate good Y_t according to the following production function:

$$Y_t = A_t M^{\alpha}_t N^{1-\alpha}_t, \tag{15}$$

where A_t is the technology shock, M_t denotes imported goods, N_t refers to labor input, and α is the share of imported goods in production. For simplicity, there is no capital in the model.[12] The total factor productivity shock is assumed to be persistent and defined via the exogenous process

$$A_t = \rho_a A_{t-1} + \varepsilon^a_t. \tag{16}$$

Firms maximize profits given the prices of inputs, i.e., the nominal wage W_t and the foreign price P^*_t adjusted by the nominal exchange rate S_t. Also, they have to finance a constant fraction of their production via bank loans in either domestic or foreign currency. For simplicity, the share of dollarization is constant and equal to the share in deposits and loans in the households' problem (λ). The profit maximization has the form

$$\begin{aligned}\max_{N_t,M_t,L^{fd}_t,L^{ff}_t} \mathcal{L}_t =& E_0 \sum_{t=0}^{\infty} \Xi_{0,t}[P^Y_t Y_t - W_t N_t - P^*_t S_t M_t + L^{fd}_t + L^{ff}_t S_t \\ & - (1+i^{ld}_{t-1})L^{fd}_{t-1} - (1+i^{lf}_{t-1})L^{ff}_{t-1} S_t],\end{aligned} \tag{17}$$

where P^Y_t is the price of intermediate goods, $W_t N_t$ and $P^*_t S_t M_t$ denote labor and imported goods costs,[13] L^{fd}_t are loans in domestic currency, L^{ff}_t are loans in foreign currency, i^{ld}_t and i^{lf}_t are the corresponding lending rates, and $\Xi_{t,s} = \beta^{s-t}\frac{\Lambda_s}{\Lambda_t}$ is the nominal pricing kernel (Andrle et al., 2009), as firms are owned by savers.

[12] For empirical work we replace consumption with the sum of consumption and investment in order to avoid excluding investment from our analysis.

[13] Intermediate firms use aggregate labor, $N_t = \gamma^s N^s_t + (1-\gamma^s)N^b_t$, and W_t is the weighted average of these two ($W_t = \gamma^s W^s_t + (1-\gamma^s)W^b_t$).

Assuming a loans-in-advance constraint

$$L_t^{fd} + L_t^{ff} S_t = L_t^f \le \kappa P_t^Y Y_t, \tag{18}$$

where κ is the fraction of nominal production required to be financed through bank loans and L_t^f denotes the total volume of loans to firms, the optimization problem becomes

$$\max_{N_t, M_t} \mathscr{L}_t = E_0 \sum_{t=0}^{\infty} \Xi_{0,t} [P_t^Y A_t M_t^{\alpha} N_t^{1-\alpha} - W_t N_t - P_t^* S_t M_t + \kappa P_t^Y A_t M_t^{\alpha} N_t^{1-\alpha}$$
$$-(1+i_{t-1}^{ld})(1-\lambda)\kappa P_{t-1}^Y A_{t-1} M_{t-1}^{\alpha} N_{t-1}^{1-\alpha} - (1+i_{t-1}^{lf})\lambda \kappa P_{t-1}^Y A_{t-1} M_{t-1}^{\alpha} N_{t-1}^{1-\alpha} \dot{S}_t]. \tag{19}$$

The first-order conditions for optimal input demands are

$$W_t N_t = (1-\alpha) P_t^Y Y_t \left[1 + \kappa - \kappa \Xi_{t,t+1} \left[(1+i_t^{ld})(1-\lambda) + (1+i_t^{lf})\lambda \dot{S}_{t+1}\right]\right], \tag{20}$$

and

$$P_t^* S_t M_t = \alpha P_t^Y Y_t \left[1 + \kappa - \kappa \Xi_{t,t+1} \left[(1+i_t^{ld})(1-\lambda) + (1+i_t^{lf})\lambda \dot{S}_{t+1}\right]\right]. \tag{21}$$

3.3.2 Final Goods Producers and Sticky Price Setting

Final goods producers, or retailers, set their prices according to Calvo contracts, so their prices are sticky.[14] A continuum j of monopolistically competitive final-goods-producing firms use domestic intermediate goods to produce final goods, which are consecutively consumed by households and the government. The production function has a simple form

$$\mathscr{Y}_t(j) = Y_t(j), \tag{22}$$

where $\mathscr{Y}_t(j)$ is the final output of the j-th producer. The profit maximization has the form

$$\max_{P_t(j), Y_t(j)} \sum_{t=0}^{\infty} \xi_p^t [P_t(j)\mathscr{Y}_t(j) - P_t^Y Y_t(j)], \tag{23}$$

where P_t is the price of final goods and $(1-\xi_p)$ is the constant probability of receiving a signal to re-optimize prices. Final goods producers face a downward-sloping demand curve for their production[15]

[14] The Calvo-Yun setup is used, introducing staggered prices into the model. Calvo (1983) develops a model in continuous time in which each firm is allowed to change its price only when it receives a random signal. Firms follow a perfect-foresight equation for the price-setting. In the Yun (1996) extension, firms maximize the present value of real profits when they set prices.

[15] The demand curve is a result of the profit maximization of a perfectly competitive (zero-profit) aggregator who puts together differentiated goods using the Dixit and Stiglitz (1977) constant-returns-to-scale production function. The assumptions of the optimization problem are described in Erceg et al. (2000). Similar assumptions are used for other monopolistically competitive sectors in the model.

$$Y_t(j = \left(\frac{P_t(j)}{P_t}\right)^{-\vartheta_p} \bar{Y}_t, \tag{24}$$

where $\bar{Y}_t$ is aggregate demand for intermediate goods as defined in equation (27) below.

Assuming full backward indexation for producers who do not receive a signal to re-optimize their prices, the first-order condition implies a hybrid version of the Phillips curve

$$\log \dot{P}_t = \frac{1}{1+\beta} \log \dot{P}_{t-1} + \frac{\beta}{1+\beta} \log \dot{P}_{t+1} + \frac{(1-\xi_p)(1-\xi_p\beta)}{\xi_p(1+\beta)} \log \left(\frac{P_t^Y * \text{markup}}{P_t}\right) + \varepsilon_t^P, \tag{25}$$

where the price of final goods is (in the long run) set as a constant markup over nominal marginal costs (P_t^Y). Thus, the expression $\log\left(\frac{P_t^Y * \text{markup}}{P_t}\right)$ can be interpreted as the real marginal cost, which can be linearized as follows:

$$rmc_t = (1-\alpha)(w_t + \Lambda_t) + \frac{1-\alpha}{1-\chi}(c_t - \chi c_{t-1}) + \alpha z_t + \Psi((1-\lambda)(r_t^{ld} - r_t^{dd}) + \lambda(r_t^{lf} - r_t^{df})) - a_t. \tag{26}$$

Final goods are used for domestic absorption only, i.e. they are not exported.[16]

$$\bar{Y}_t = C_t + G_t. \tag{27}$$

3.4 Banking Sector

The deposit and credit flows in the model are carried out by the banking sector, i.e., firms and households cannot borrow directly from international markets. Similarly, net saver households are only allowed to hold deposits in domestic banks.

The model includes two layers of banks: wholesale and retail ones.[17] First, a representative wholesale bank collects deposits from households, borrows from abroad, extends loans to retail banks, and purchases government bonds. Households' deposits and foreign borrowing are substitutes on wholesale banks' liability side. Similarly, households' loans and firms' loans are perfect substitutes on the asset side.

Second, retail banks purchase loans from wholesale banks, differentiate them, and extend them to firms and households. Retail banks face a rare opportunity to change the price – the interest rate – of loans and deposits. Retail interest rates are staggered.

3.4.1 Wholesale Banks

To illustrate wholesale banks' role in the model, we show the decomposition of banks' balance sheet and banks' asset and liability flows in the following Tables 1 and 2. All variables specific to the wholesale banking sector are denoted by tilde.

[16] Note also the difference between domestic absorption $\bar{Y}_t$ and Y_t, which represents overall GDP.

[17] This assumption is more of a technical one. It just simplifies the derivation of the model and does not represent the segmentation of banks in the Serbian financial market.

Table 1: Banks' Balance Sheet

Assets			Liabilities
Loans to households in local currency	$\tilde{L}_t^{hd}$	$\tilde{D}_t^d$	Deposits from households in local currency
FX loans to households	$\tilde{L}_t^{hf} S_t$	$\tilde{D}_t^f S_t$	FX deposits from households
Loans to firms in local currency	$\tilde{L}_t^{fd}$	$\tilde{F}_t^B S_t$	Borrowing from abroad
FX loans to firms	$\tilde{L}_t^{ff} S_t$		
Government bonds	$\tilde{B}_t$		
Required reserves	$rrS_t(\tilde{D}_t^f + \tilde{F}_t^B)$		

Table 2: Banks' Asset and Liability Flows

Revenues	Expenses
$(1+i_{t-1}^{bd})\tilde{L}_{t-1}^{hd}$ - $\tilde{L}_t^{hd}$	$(1+i_{t-1}^{dd})\tilde{D}_{t-1}^{d}$ - $\tilde{D}_t^d$
$(1+i_{t-1}^{bf})\tilde{L}_{t-1}^{hf}S_t$ - $\tilde{L}_t^{hf}S_t$	$(1+i_{t-1}^{df})\tilde{D}_{t-1}^{f}S_t$ - $\tilde{D}_t^f\ S_t$
$(1+i_{t-1}^{bd})\tilde{L}_{t-1}^{fd}$ - $\tilde{L}_t^{fd}$	$(1+i_{t-1}^{*})(1+Prem_{t-1})\tilde{F}_{t-1}^{B}S_t$ - $\tilde{F}_t^B\ S_t$
$(1+i_{t-1}^{bf})\tilde{L}_{t-1}^{ff}S_t$ - $\tilde{L}_t^{ff}S_t$	$fc(\frac{\tilde{L}_t+\tilde{B}_t}{\tilde{D}_t})$
$(1+i_{t-1}^{bd})\tilde{B}_{t-1}$ - $\tilde{B}_t$	
$rr(\tilde{D}_{t-1}^f S_t+\tilde{F}_{t-1}^B S_t) - rr(\tilde{D}_t^f S_t + \tilde{F}_t^B S_t)$	

The wholesale banks maximize their profits

$$\max_{\tilde{D}_t^d,\tilde{D}_t^f,\tilde{F}_t^B,\tilde{L}_t^{hd},\tilde{L}_t^{hf},\tilde{L}_t^{fd},\tilde{L}_t^{ff},\tilde{B}_t} \sum_{t=0}^{\infty} \Xi_{0,t}\{\tilde{D}_t^d + \tilde{D}_t^f S_t + \tilde{F}_t^B S_t - \tilde{L}_t^{hd} - \tilde{L}_t^{fd} - (\tilde{L}_t^{hf}+\tilde{L}_t^{ff})S_t - \tilde{B}_t$$
$$- rr(\tilde{D}_t^f S_t + \tilde{F}_t^B S_t) + rr(\tilde{D}_{t-1}^f S_t + \tilde{F}_{t-1}^B S_t)$$
$$+ (1+i_{t-1}^{bd})(\tilde{L}_{t-1}^{hd}+\tilde{L}_{t-1}^{fd}) + (1+i_{t-1}^{bf})(\tilde{L}_{t-1}^{hf}+\tilde{L}_{t-1}^{ff})S_t + (1+i_{t-1}^{bd})\tilde{B}_{t-1}$$
$$- (1+i_{t-1}^{dd})\tilde{D}_{t-1}^d - (1+i_{t-1}^{df})\tilde{D}_{t-1}^f S_t - (1+i_{t-1}^{*})(1+Prem_{t-1})S_t\tilde{F}_{t-1}^B - fc\left(\frac{\tilde{L}_t+\tilde{B}_t}{\tilde{D}_t}\right)\}, \quad (28)$$

subject to the balance sheet constraint

$$\tilde{L}_t^{hd} + \tilde{L}_t^{hf}S_t + \tilde{L}_t^{fd} + \tilde{L}_t^{ff}S_t + \tilde{B}_t + rr(\tilde{D}_t^f S_t + \tilde{F}_t^B S_t) = \tilde{D}_t^d + \tilde{D}_t^f S_t + \tilde{F}_t^B S_t. \quad (29)$$

On the liability side of the balance sheet, banks borrow from abroad ($\tilde{F}_t^B$) and collect deposits from households in both foreign currency ($\tilde{D}_t^f S_t$) and domestic currency ($\tilde{D}_t^d$). On the asset side, banks extend loans to firms denominated in domestic ($\tilde{L}_t^{fd}$) and foreign currency ($\tilde{L}_t^{ff} S_t$), as well as loans to households denominated in domestic ($\tilde{L}_t^{hd}$) and foreign currency ($\tilde{L}_t^{hf} S_t$), invest in government bonds ($\tilde{B}_t$), and hold a certain required reserve ratio (rr) of FX liabilities at the central bank. The required ratio is assumed to be constant.

On the one hand, banks pay interest rates i_t^{dd} on deposits in domestic currency and i_t^{df} on deposits in foreign currency, where the latter is a function of foreign interest rates (i_t^*) and the country risk premium ($Prem_t$). On the other hand, they receive interest rates i_t^{bd} on loans in domestic currency and government bonds, and i_t^{bf} on loans in foreign currency. $fc(\frac{\tilde{L}_t+\tilde{B}_t}{\tilde{D}_t})$ is a penalty cost function that implies lower profits when a bank does not maintain the exogenously set loan-to-deposit target. The exact specification of the cost function is not needed, as only its derivatives are necessary for the interest rate dynamics (Roger and Vlcek, 2011). These costs are paid to the government and are thus assumed to be private, not social.

After rearranging, the optimality conditions constitute the UIP equations adjusted by the derivative of the penalty function[18] and the reserve requirements

$$(1+i_t^{dd}) = (1+i_t^*)(1+Prem_t)\dot{S}_{t+1}\frac{1}{1-rr} - \frac{rr}{1-rr}\dot{S}_{t+1} + \left(\frac{\tilde{L}_t^d+\tilde{L}_t^f+\tilde{B}_t}{\tilde{D}_t} - \eta\right)\omega_1, \tag{30}$$

and

$$(1+i_t^{bd}) = (1+i_t^*)(1+Prem_t)\dot{S}_{t+1}\frac{1}{1-rr} - \frac{rr}{1-rr}\dot{S}_{t+1} + \left(\frac{\tilde{L}_t^d+\tilde{L}_t^f+\tilde{B}_t}{\tilde{D}_t} - \eta\right)\omega_2, \tag{31}$$

where η is the loan-to-deposit ratio requirement and ω_1 and ω_2 are scaling parameters. Thus, the penalty costs provide a closing mechanism for the model by balancing deposits and loans in the economy. If banks face high demand for loans, increasing both lending rates will encourage saving and, at the same time, discourage borrowing. Such a mechanism is similar to the debt-elastic premium described in Schmitt-Grohe and Uribe (2001).[19] Note that if the reserve requirement rate goes to zero, and without a loan-to-deposit ratio requirement, (30) and (31) transform into the pure UIP condition.

Rearranging the first-order conditions with respect to loans and deposits in foreign currency, and assuming that $fc'(\tilde{D}^f)$ and $fc'(\tilde{L}^f)$ equal zero, gives

$$(1+i_t^{df}) = (1+i_t^*)(1+Prem_t), \tag{32}$$

$$(1+i_t^{bf}) = (1+i_t^*)(1+Prem_t)\frac{1}{1-rr_t} - \frac{rr}{1-rr}. \tag{33}$$

Note that under the assumption that $Prem_t$, i_t^* and $\dot{S}_{t+1} - 1 = \Delta s_{t+1}$ are reasonably small, so that their products are close to zero, (30)–(33) can be rewritten in more economically intuitive forms:

$$i_t^{dd} = \frac{i_t^*+Prem_t}{1-rr} + \Delta s_{t+1} + \left(\frac{\tilde{L}_t^d+\tilde{L}_t^f+\tilde{B}_t}{\tilde{D}_t} - \eta\right)\omega_1, \tag{34}$$

$$i_t^{df} = \frac{i_t^*+Prem_t}{1-rr} + \Delta s_{t+1} + \left(\frac{\tilde{L}_t^d+\tilde{L}_t^f+\tilde{B}_t}{\tilde{D}_t} - \eta\right)\omega_2, \tag{35}$$

$$i_t^{df} = i_t^* + Prem_t, \tag{36}$$

$$i_t^{bf} = \frac{i_t^*+Prem_t}{1-rr}. \tag{37}$$

[18] The derivative of the cost function with respect to domestic deposits is $[fc(\frac{L+B}{D})]' = -fc'(D)$ and the derivative with respect to foreign deposits is assumed to be zero, i.e., $[fc(\frac{L+B}{D})]' = 0$.

[19] In the model equations, we modify the UIP condition to introduce some inertia into the reaction of the nominal exchange rate to shocks.

It is important to stress that (34) gives a UIP relationship, i.e., how the spread between domestic and FX deposit rates affects the exchange rate dynamics. The RSD deposit rate itself is basically determined by the NBS key policy rate:

$$i_t^{dd} = i_t^{mp} - Prem_t^{dd}, \tag{38}$$

where $Prem_t^{dd}$ refers to the spread between the policy rate and the interest rate on deposits in the local currency. The strong relationship between the two rates is obvious from Figure 4.

3.4.2 Retail Banks

There is a continuum k of monopolistically competitive retail banks which purchase loans from wholesale banks, differentiate them, and extend them to households and firms. The assumption of monopolistic competition introduces stickiness into lending rates. The intuition behind this is similar to the price stickiness described in Section 3.3.2. Following Benes and Lees (2007), there is a probability to re-optimize the lending rate $(1-\xi_n)$, where $n \in d,f$ refers to loans denominated in the domestic and foreign currencies. Retail banks are endowed with a linear production function. The profit maximization is

$$\max_{i_t^{ln}(k)} \sum_{t=0}^{\infty} \xi_n^t [(1+i_t^{ln}(k))L_t^n(k) - (1+i^{bn})L_t^n(k)], \tag{39}$$

subject to the downward-sloping demand curve

$$L_t^n(k) = \left(\frac{1+i_t^{ln}(k)}{1+i_t^{ln}}\right)^{\frac{\theta}{1-\theta}} \tilde{L}_t^n, \tag{40}$$

where θ determines the interest rate elasticity of demand.

The first-order conditions imply a Phillips curve-type of equation for both interest rates

$$i_t^{ld} = \frac{1}{1+\beta} i_{t-1}^{ld} + \frac{\beta}{1+\beta} i_{t+1}^{ld} + \frac{(1-\xi_d)(1-\xi_d\beta)}{\xi_d(1+\beta)} \left(\frac{i_t^{bd} + Sprd^d}{i_t^{ld}}\right), \tag{41}$$

$$i_t^{lf} = \frac{1}{1+\beta} i_{t-1}^{lf} + \frac{\beta}{1+\beta} i_{t+1}^{lf} + \frac{(1-\xi_f)(1-\xi_f\beta)}{\xi_f(1+\beta)} \left(\frac{i_t^{*} + Prem_t + Sprd^f}{i_t^{lf}}\right), \tag{42}$$

where $Sprd^d$ and $Sprd^f$ denote the spreads (markup) within the banking sector on domestic and foreign loans, respectively.

Finally, the total supply of loans and deposits equals demand. The following identities therefore hold:

$$\tilde{L}_t^n = L_t^n, \tag{43}$$

$$\tilde{D}_t^m = D_t^m, \tag{44}$$

$$\tilde{F}_t^B = F_t^B, \tag{45}$$

$$\tag{46}$$

where $n \in \{hd, hf, fd, ff\}$ and $m \in \{d, f\}$.

3.5 Central Bank

The central bank targets year-on-year headline inflation ($\log \dot{P}4$) four periods ahead using the policy rate (1-week BELIBOR).

The central bank's reaction function has the form

$$i_t^{mp} = \phi_i i_{t-1}^{mp} + (1-\phi_i)(\bar{r}_t^{mp} + \log \dot{P}_t^{target} + \phi_p(\log \dot{P}4_{t+4} - \log \dot{P}_{t+4}^{target})) + \varepsilon_t^{mp}, \tag{47}$$

where i_t^{mp} is the key policy rate of the NBS, $\bar{r}_t^{mp}$ is the equilibrium real interest rate, $\log \dot{P}_t^{target}$ is the inflation target, and the term in parentheses denotes the deviation of inflation from the target four periods ahead. The parameter ϕ_i denotes interest rate smoothing and ϕ_p is the weight on the deviation from the inflation target (the reactiveness of the monetary authority). The monetary policy shock is ε_t^{mp}.

3.6 Government

The government collects lump-sum taxes, receives bank penalty payments, issues bonds, and consumes final (government) goods. Its budget constraint is

$$P_t G_t + (1 + i_{t-1}^{bd}) B_{t-1} = B_t + \Gamma_t, \tag{48}$$

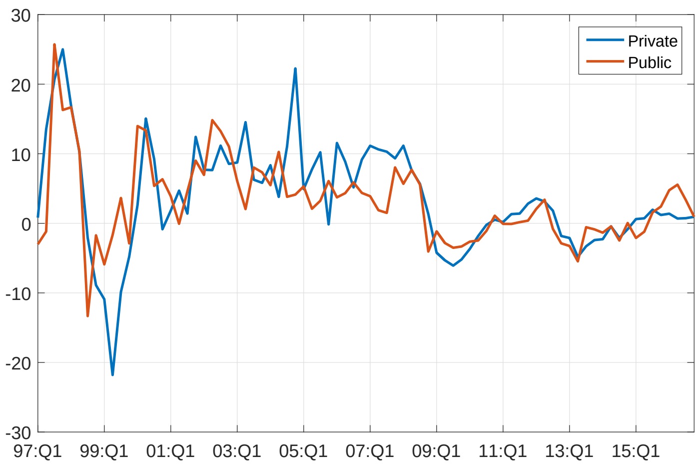
where Γ_t denotes lump-sum taxes adjusted for penalty payments from banks. The government budget constraint does not constitute a fiscal policy rule (see Andrle et al., 2009). The ratio of government bonds to government spending is assumed to be constant.

The government adjusts its spending to keep the ratio of its nominal expenditures to the nominal consumption of households constant. This simple rule is in line with the empirically observed constant ratio of private to public consumption.

$$\frac{P_t G_t}{P_t C_t} = \left(\frac{P_{t-1} G_{t-1}}{P_{t-1} C_{t-1}}\right)^{\rho_g} \left(\frac{PG}{PC}\right)^{1-\rho_g} \exp(\varepsilon_t^G). \tag{49}$$

This simple fiscal rule is consistent with the empirically observed strong correlation between private and government consumption growth (see Figure 6).

Figure 6: YoY Growth of Private and Government Consumption (in percent)



3.7 Rest of the Model

3.7.1 Exports

The real export function is standard, relating real exports to foreign demand and the real exchange rate, approximating the price competitiveness of exporting firms:

$$X_t = X_{t-1}^{\rho_x} \left(\frac{P_t^*}{P_t^X / S_t} \right)^{\omega_x} (Y_t^*)^{\omega_{y^*}} \exp(\varepsilon_t^X), \tag{50}$$

where parameter ρ_x determines the persistence of demand for exports, ω_x is the sensitivity of demand for exports to relative price changes, and ω_{y^*} is the scaling parameter for foreign demand.

The price of exports, P_t^X, is independent of domestic business cycles and is determined in international markets.[20] The price of exports is derived from the terms of trade.

The terms of trade follow the autoregressive process

$$TOT_t = TOT_{t-1}^{\rho_{tot}} \exp(\varepsilon_t^{tot}), \tag{51}$$

implying that they are linked with the price of exports

$$TOT_t = \frac{P_t^X}{P_t^* S_t}. \tag{52}$$

Foreign demand is set as an exogenous AR(1) process.

$$Y_t^* = Y_{t-1}^{\rho_{y^*}} \exp(\varepsilon_t^{Y^*}). \tag{53}$$

[20] This feature enables us to capture the counter-cyclical behavior of the trade balance in developing economies (Aguiar and Gopinath, 2004), as model exports are exogenous and model imports are pro-cyclical.

3.7.2 Net Foreign Asset Accumulation

From the household budget constraint, the government budget constraint, and the profits of monopolistically competitive firms and banks, it is possible to acquire an equation for net foreign assets

$$F_t^B = F_{t-1}^B(1+i_{t-1}^*)\dot{S}_t(1+Prem_{t-1}) - P_t^X X_t + P_t^* S_t M_t, \tag{54}$$

where a positive value of net foreign assets F_t^B implies that the country is a net debtor.

3.7.3 Risk Premium

The risk premium adjusts to the level of, and the change in, the net foreign asset position of the country. The underlying intuition is that the net foreign asset position affects the country's level of foreign borrowing, which further drives up the risk premium and therefore the country's interest expenses. The equation describing the law of motion for the risk premium is given in the following form:

$$Prem_t = \rho_{Prem} Prem_{t-1} + (1-\rho_{Prem})(\omega_p(F_t^B - F_{t-1}^B) + \omega_{pl} F_t^B) + \varepsilon_t^{premia}, \tag{55}$$

where ω_p determines the sensitivity of the country risk premium to changes in foreign borrowing and ω_{pl} drives the response of the country risk premium to the level of foreign borrowing.

4. Model Properties

An examination of the model properties allows us to assess to what extent the model captures the aggregate business cycle features (stylized facts) of the Serbian economy. During this process, we tried to replicate and further supplement the features of the existing QPM model of the NBS while also taking into account the empirical evidence and underlying economic logic.

The model-consistent filtration, resulting in estimated gaps and trends in the historical data, was carried out using the Kalman filter.[21] This is presented in Section 4.3. Particular attention was paid to parameter calibration and estimation, which are shown in Section 4.1. In order to assess the model's dynamic properties, we first carried out impulse response analyses, the results of which are presented in Section 4.2.

4.1 Calibration and Sensitivity Analysis

The parameters of the model were calibrated.[22] During the calibration phase, several criteria were used to specify the parameter values, e.g., sensitivity and impulse response analysis, expert judgment, conformity with the literature, and other countries' experiences.

We can divide the model parameters into four groups: 1) steady-state parameters, which determine the properties of the model in the long run i.e., along the balanced growth path, 2) steady-state shares, 3) transient parameters determining the short-run dynamics of the model, and 4) persistence.

The steady-state parameters were mostly calibrated by taking into account recent trends while also employing expert judgment. Their values are given in Table A1.

The calibration of the transient parameters is carried out by inspecting the model's impulse responses and performing a sensitivity analysis to establish theoretically grounded behavior of the model and reflect specific features of the Serbian economy. The values for these parameters are given in Table A2.

Due to macroeconomic volatility experienced during the 1990s, the Serbian economy is highly euroized. This implies a weaker interest rate channel, resulting in a reduced ability of the central bank to affect interest rates on FX deposits and loans. In our case, the level of euroization is 85% for deposits and 73% for loans. However, since we did not explicitly differentiate the two within the model, we chose to set the value for the level of euroization at 76%, taking into account the fact that the total volume of loans is significantly higher than the total volume of deposits. Since we assume a constant euroization level in the model, relatively stable observed values over time are consistent with the model specification (see Figure 2).

As shown in Fuhrer (2000), in order to successfully account for the hump-shaped response of consumption to various shocks, it is necessary to introduce habit formation in consumption. Its introduction reflects the fact that consumers, while reacting to shocks hitting the economy, wish to smooth the level of consumption, thus contributing to more sluggish responses of consumption. We set different values of habit formation in the model for the two types of households. Net savers

[21] The use of a multivariate procedure is convenient as it does not require any pre-filtering of the data, including demeaning. The model is handled via the IRIS Toolbox (Benes, 2014).

[22] A small proportion of the parameters were estimated by OLS regression. This was used for the persistence of exogenous variables and some long-run trends.

are less likely to change their consumption pattern, so their habit formation parameter is set to 0.8, compared to 0.3 for borrowers.

Price rigidities are introduced following Calvo's approach, with the probability of an arbitrary firm receiving a signal to re-optimize the price calibrated at 0.35. This implies that firms change their prices approximately every nine months, which is more frequent in comparison with the whole euro area, as documented in Smets and Wouters (2003), and some countries of the Eurozone (see Levy and Smets, 2010).[23]

Since the Serbian economy is a small open economy with significant dependence on inflows of foreign capital, the sensitivity of the country risk premium to the share of foreign borrowing in total consumption has an important role in explaining its dynamic response to various shocks. We set this parameter to 0.005, which is the value that implies desirable effects and behavior of the model.

Proper calibration of the parameters representing the penalty costs for the banking sector in the extended uncovered interest rate parity equation turns out to be very important for obtaining plausible properties of the model. Higher penalty parameters put more weight on the loan-to-deposit requirement in determining deposit and lending rates. Depending on the spreads between those rates, this affects the real marginal costs of firms and therefore overall inflation. By employing sensitivity analysis, we determined the values of these parameters to be 0.03 in the equation for domestic deposit rates and 0.02 for wholesale rates on loans.

The estimated parameters include persistence for trend growth of the real variables in the model. These are shown in Table A3 along with the persistence which appears in the structural equations.

The ratios in the model are calculated mostly by taking into account the recent data, but also account for the structural breaks that occurred in the aftermath of the global financial crisis of 2008. They are presented in Table A4.

[23] For instance, Italian and Portuguese firms have a tendency to change their prices every ten and twelve months, respectively. On the other hand, Slovakia and Romania exhibit more frequent price changes, at intervals of approximately four and five months, respectively. For the Czech Republic, Murarik (2011) calculates the implicit length of periods without price changes (due, for example, to a change of store or a change in the specific type of product) for all selected items at ten to eleven months.

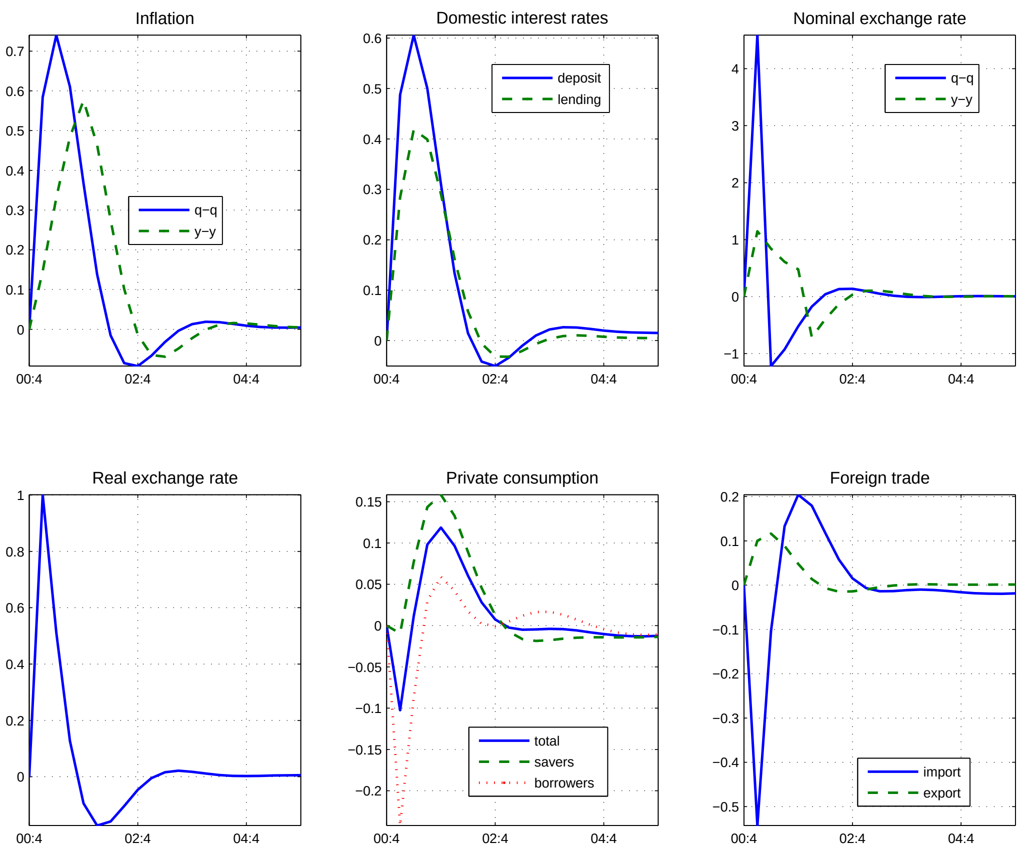
4.2 Impulse Responses

Unexpected depreciation

An unexpected nominal depreciation has strong real consequences in a euroized/dollarized economy. Given foreign currency borrowing, any depreciation raises the repayment costs of borrowers. As a result of the nominal depreciation, borrowers reduce their consumption.

This behavior is demonstrated by an unexpected exchange rate depreciation shock which depreciates the nominal exchange rate by 1 percent initially (an annualized depreciation of 4 percent). The one-off depreciation shock leads to a pickup in the inflation rate, triggering monetary policy tightening by the central bank. Both the deposit rate and the lending rate in local currency go up. While savers keep their consumption almost unchanged initially, borrowers reduce their spending. The reduction is driven by higher domestic lending rates in the case of domestic borrowers and also by the higher repayment costs of those who borrowed in foreign currency. Besides households, foreign-currency-borrowing firms also face higher repayment costs due to the nominal depreciation. This creates additional upward pressures on domestic prices. Overall consumption improves in the subsequent periods, as inflation is expected to rise, reducing real deposit and lending rates.

Figure 7: Nominal Exchange Rate Shock (Deviations in percent/p.p. from Steady State)

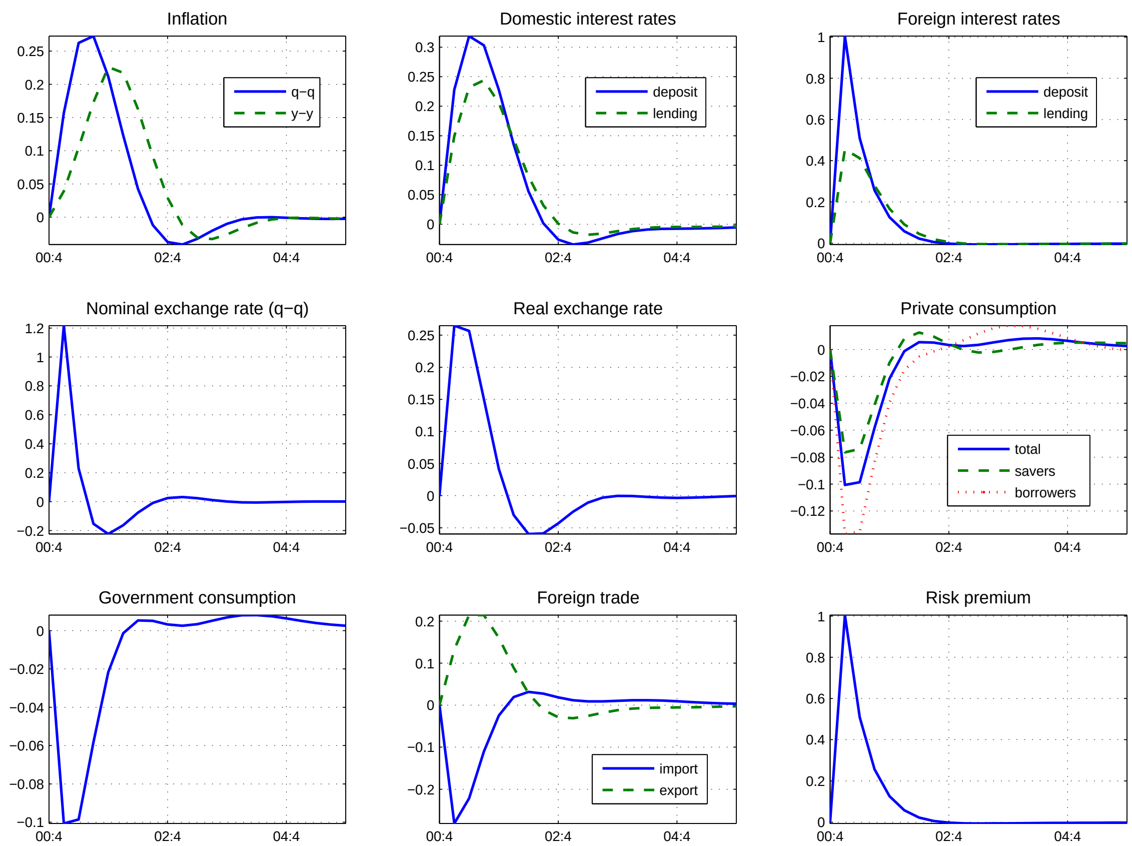


Risk Premium Shock

High capital mobility makes economies vulnerable to risk premium shocks. As can be seen from Figure 8, as a direct result of a rise in the country risk premium of 1%, FX interest rates in

Serbia go up and the domestic currency consequently depreciates on impact. The depreciation leads to a higher inflation rate, triggering monetary policy tightening. The higher interest rates (both domestic and FX) have a negative impact on domestic consumption (mitigating the inflation pressures stemming from the depreciation), but on the other hand this is offset by an improvement in net exports caused by real depreciation of the dinar. The shock eventually fades away as the risk premium converges back to the steady state.

Figure 8: Risk Premium Shock (Deviations in percent/p.p. from Steady State)

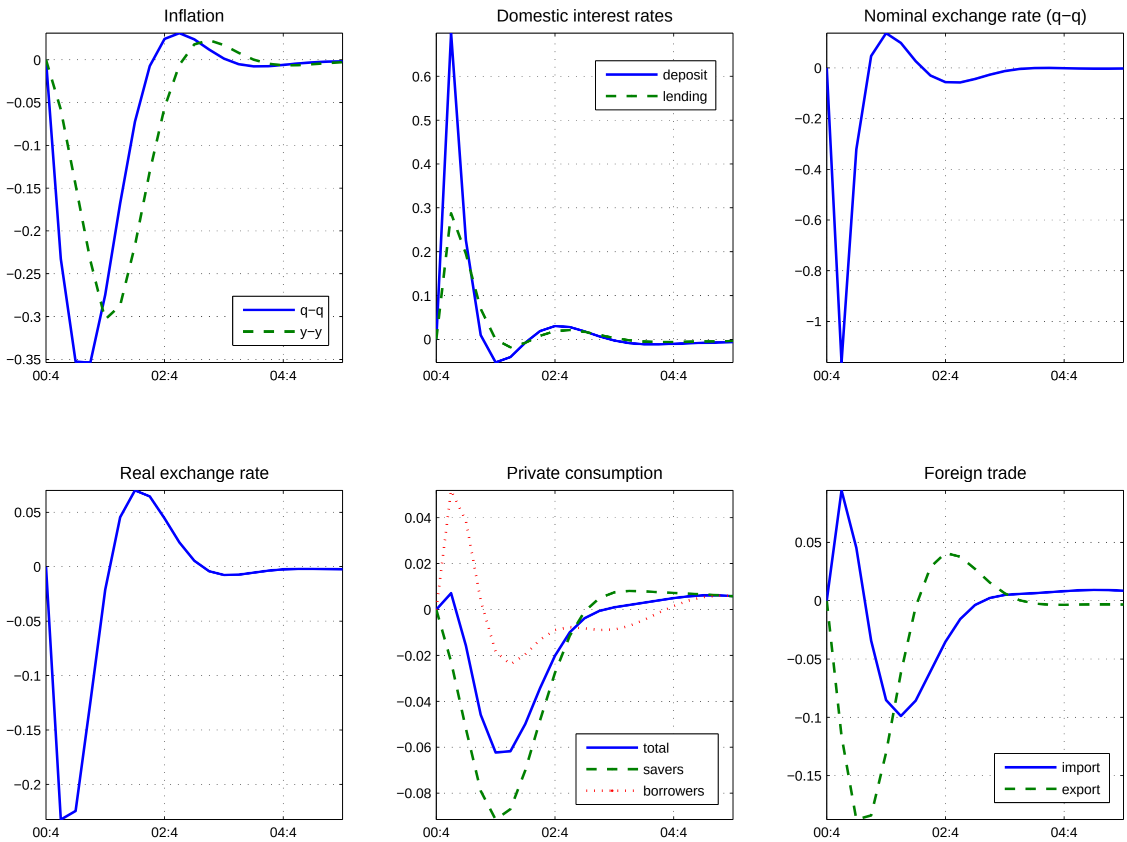


Increase in Policy Rate

Changes in the policy rate pass through two main channels – the FX channel and the interest rate channel. We assume an unexpected shock to the policy rate of 100 bp. First, raising the policy rate leads to nominal appreciation of the dinar through the UIP. This implies real appreciation, thus creating disinflationary pressures through lower real marginal costs, but also negatively affecting GDP due to impaired external competitiveness. At the same time, the high real interest rate is a disincentive to consumption. As a result, there are negative effects on GDP along with the disinflationary pressures. Note that in the case of borrowers' consumption, the initial effect of the shock is positive, as their installment payments become lower due to the nominal appreciation (see Figure 9).

Because of euroization, however, the effect of the interest rate channel on inflation is significantly weaker than the effect of the FX channel.

Figure 9: Increase in Policy Rate (Deviations in percent/p.p. from Steady State)

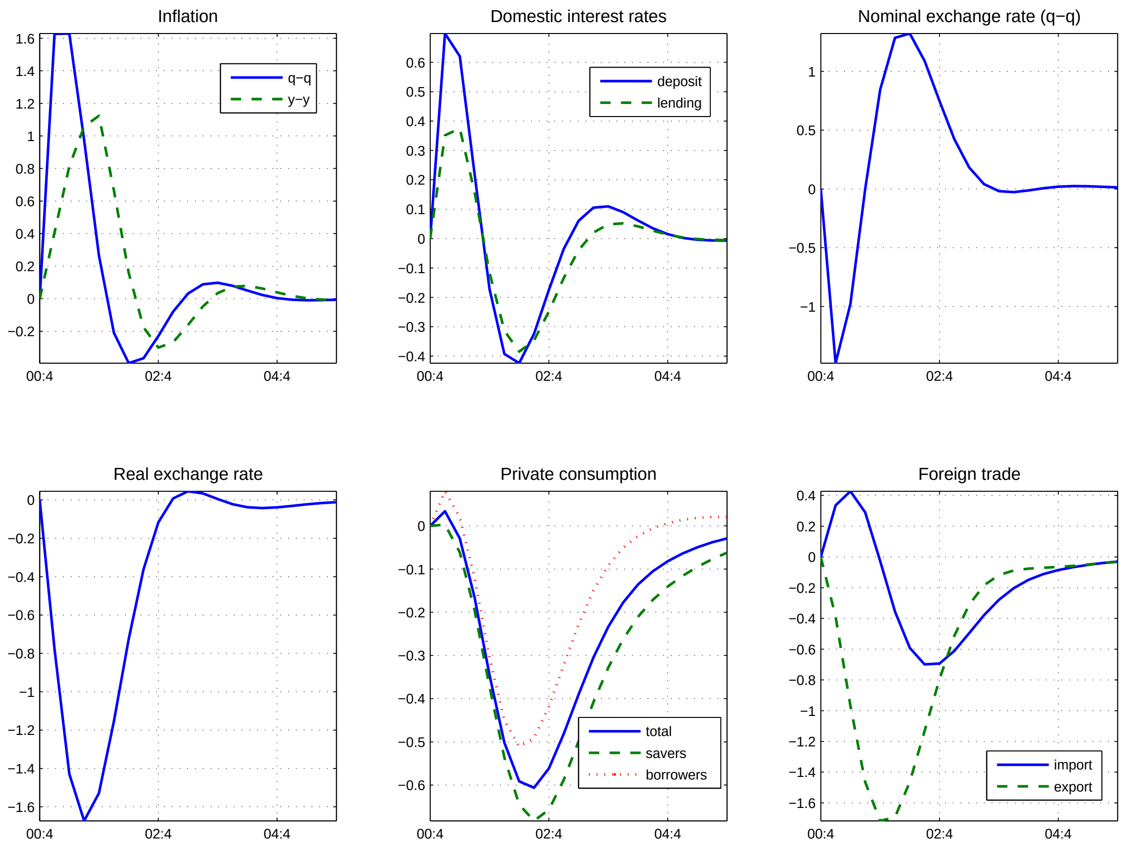


Inflation (Cost-push) Shock

Unexpected shocks to inflation are frequent and are caused by factors of both external and internal origin. In many cases, these shocks are related to a single component of the consumer basket.

A 1 p.p. shock to quarterly inflation (see Figure 10) leads to an increase in y-o-y inflation which, due to its persistence, reaches its peak three quarters afterwards. The central bank gradually raises its key policy rate, reacting to y-o-y inflation four periods ahead. This reaction leads to nominal exchange rate appreciation, which, together with rising inflation, results in real exchange rate appreciation. The subsequent fall in price competitiveness is the main driving force behind worsening net exports, which, in turn, are the main reason why real GDP reaches a trough one year after the initial shock. At the same time, the real exchange rate appreciation lowers the real marginal costs of intermediate goods producers, contributing further to disinflation. Initially higher real deposit rates make spending less favorable, implying a gradual fall in consumption as well as prices.

Figure 10: Inflation Shock (Deviations in percent/p.p. from Steady State)



4.3 Putting the Model to the Serbian Data

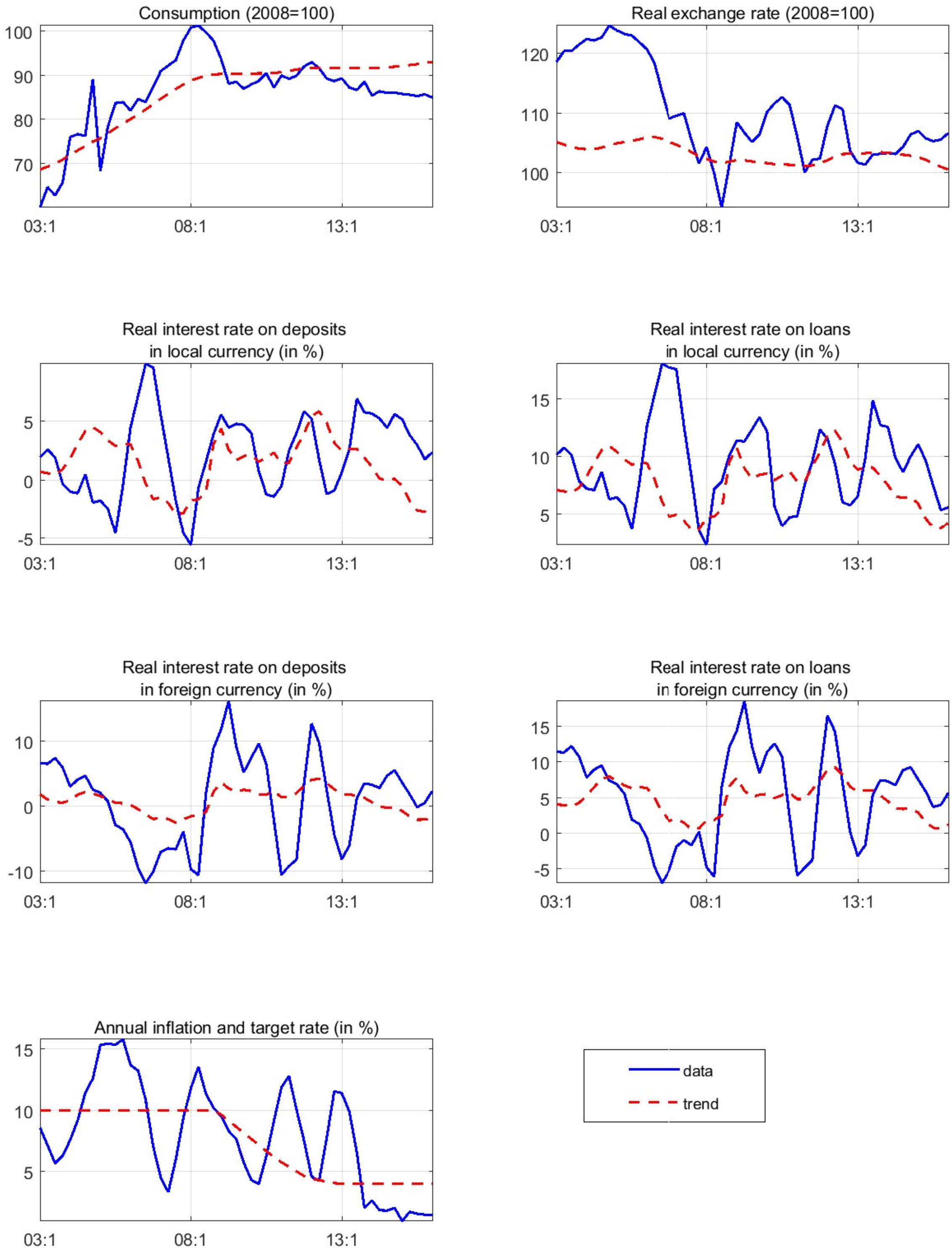
Filtering the Data

The model presented in the previous sections is stationary, showing no growth in the steady state. In order to match the data, the model is enriched by simple equations for trends. These state that the trend in a variable converges to its steady state with some persistence. There are also links among different trends, such as the real UIP equation, which links the real Serbian interest rate (IR) to the real Eurozone IR, the risk premium, and the RER trend. We are not going to go into the details of these equations here. Instead, we will present the filtration of some of the variables in the following charts.

For the purpose of matching the model with the data, we use the standard two-sided Kalman filter (Harvey, 1990; Hamilton, 1994). The plausibility of the model is assessed by inspecting the filtration results rather than by using formal likelihood-based estimation methods. More specifically, parameters of the model which are outputs of the calibration and sensitivity analysis are considered as already given in the Kalman filtering process. The standard deviations of the residuals and the measurement errors are calibrated to match the data moments and the macroeconomic story. To this end, a shock decomposition is conducted and checked for consistency with economic intuition.

The filtration is done in a model-consistent way, meaning that the estimated gaps (consumption, interest rates, …) and trends (premium, interest rate equilibrium, …) of the variables are related in the way we described in the equations in Section 3.

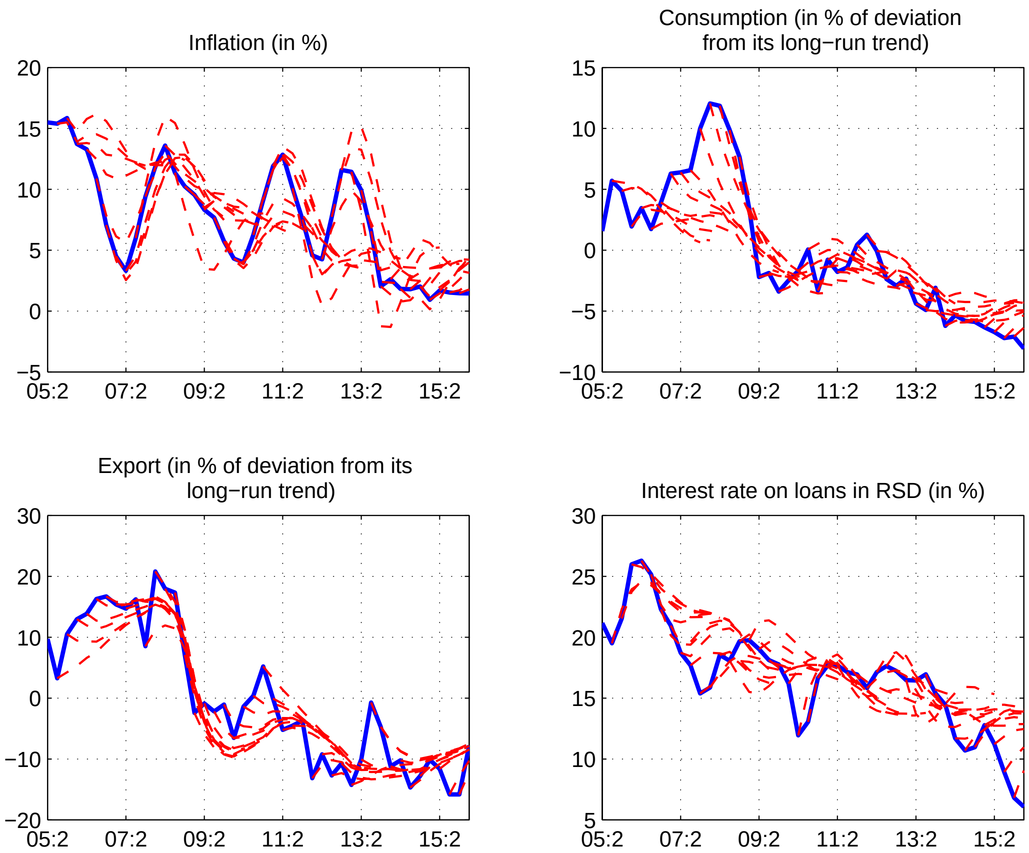
Figure 11: Filtered Data



4.4 Historical Simulations

The purpose of the historical simulations is to check how the model would have predicted the variables in certain past periods. In the case of non-stationary series, we focus on business cycle movements, i.e., gaps. Here, we present how the model explains inflation, the consumption gap, the export gap, and the domestic lending rate. As models are just a simplification of reality, historical simulations are far from perfect, but we can say that the variables are reasonably well predicted. We have to add at this point that this model is intended to be used not for forecasting, but rather for simulation (impulse response) purposes, so in calibrating the model we put more emphasis on the latter.

Figure 12: Historical In-sample Simulations



5. Conclusion

The main goal of this paper was to present the results of a technical cooperation project between the Czech National Bank and the National Bank of Serbia (NBS) focusing on the development of a dynamic stochastic general equilibrium (DSGE) model incorporating financial euroization. The model was developed to serve as complementary analytical tool in the NBS's Monetary Analyses and Statistics Department. Some of the modeling choices (constant steady-state shares of financial euroization, exogenous exports, etc.) reflect the preference of the authors to keep the model tractable. The model captures the main features of the transmission of monetary policy and various shocks in a highly euroized economy, such as the Serbian one, with inflation targeting as a strategy of the central bank. The financial euroization in the model means that banks collect deposits from saver households (not firms, for reasons of simplicity) in the domestic currency (RSD) and foreign currency (EUR) and extend loans to borrower households and firms, also in both RSD and EUR.

In the final derivation of the model, the FX deposit rate and FX lending rate are functions of the interest rate on foreign (EUR) bonds and a country risk premium, as well as a required reserve ratio (RRR). The central bank uses its policy rate (set by the Taylor rule) as its main monetary policy instrument. The policy rate has a one-to-one impact on the RSD deposit rate and an indirect effect on interest rates on RSD loans.

The properties of the model, i.e., the impulse responses, are broadly in line with the theory for dollarized economies and the observed relationships between variables in Serbia. A negative risk premium shock leads to an increase in FX-indexed rates, inducing depreciation of the dinar and higher inflation pressures and therefore triggering monetary policy tightening. A depreciation, on the one hand, leads to an improvement in net exports, but, on the other hand, together with higher interest rates, dampens domestic demand.

The fact that 70% of loans are FX-indexed obviously makes the interest rate channel weaker, while the bulk of the transmission goes through the exchange rate. However, even the latter is mitigated by the reaction of borrowing households. In the case of a depreciation of the domestic currency, this is due to a reduction in their consumption, as their current interest payment burden on EUR-indexed loans expressed in RSD goes up.

The coefficients of the model were calibrated so as to get reasonable impulse responses and to try to explain the data behavior for Serbia as much as possible. Estimating the model using the Bayesian estimation technique is one of the tasks that lie ahead as longer time series become available (some of the data are only available since 2010).

As the model is in gap form, putting it to the data was quite challenging. Filtering the data in order to extract gaps was done in a model-consistent way. We admit, however, that the explanation of the data requires further work. Despite that, we consider the model to be a useful tool for analyzing the relationships between the variables for a highly dollarized economy, especially having in mind the complexity of the channels in such an economy. In this regard, the model complements the existing QPM model, which covers inflation in much more detail but is less detailed when it comes to monetary policy channels and euroization.

To conclude, we see this stage as just the beginning of the process of developing a DSGE model for Serbia. Further development of equations, recalibration to better fit the data, and/or Bayesian estimation of the coefficients are the main future tasks relating to the model presented in this paper.

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Appendix A: Calibrated Values of Parameters

Table A1: Calibrated Values of Steady-state Parameters

Parameter	Value
Private consumption growth	2%
Government consumption growth	1.5%
Export growth	9%
Import growth	6%
Terms of trade growth	0%
Real exchange rate growth	0%
Real interest rate on domestic deposits	2.5%
Real interest rate on foreign deposits	1.9%
Real interest rate on domestic loans	8.9%
Real interest rate on foreign loans	5.9%
Foreign real interest rate	0%
Domestic inflation target	4%
Foreign inflation target	2%
Risk premia	2.5%

Table A2: Calibrated Values of Transient Parameters

Parameter	Value
Monetary policy persistence	0.65
Reaction coefficient to deviation from target	2
Share of imports in domestic intermediate production	0.65
Discount factor	0.99
Habit formation (savers)	0.8
Habit formation (borrowers)	0.3
Share of foreign currency deposits in total deposits	0.76
Sensitivity of country risk premium to growth in ratio of foreign borrowing to consumption	0
Sensitivity of country risk premium to level of ratio of foreign borrowing to consumption	0.005
Penalty parameter of banking sector for i_t^{dd}	0.05
Penalty parameter of banking sector for i_t^{bd}	0.02
Elasticity of exports with respect to real exchange rate	0.1
Elasticity of exports with respect to foreign demand	1.5
Lending rate stickiness – domestic currency	0.4
Lending rate stickiness – foreign currency	0.4
Price stickiness	0.65
Wage stickiness	0.8

Table A3: Estimated Parameters – Autoregressive Coefficients for Trend Growth in Real Variables in the Model

Parameter	Value
Autoregressive coefficient for trend growth in private consumption	0.65
Autoregressive coefficient for trend growth in government consumption	0.46
Autoregressive coefficient for trend growth in exports	0.7
Autoregressive coefficient for trend growth in imports	0.73
Autoregressive coefficient for trend growth in real exchange rate	0.5
Autoregressive coefficient for trend growth in terms of trade	0.83
Autoregressive coefficient for trend growth in real interest rate on domestic deposits	0.76
Autoregressive coefficient for trend growth in real interest rate on foreign deposits	0.76
Autoregressive coefficient for trend growth in real interest rate on domestic loans	0.63
Autoregressive coefficient for trend growth in real interest rate on foreign loans	0.69

Table A4: Ratios in the Model

Parameter	Value
Ratio of private consumption to total consumption	82%
Ratio of government consumption to total consumption	18%
Ratio of nominal exports to nominal foreign borrowing	46%
Ratio of nominal imports to nominal foreign borrowing	76.5%
Ratio of loans to total loans	87%
Loan-to-deposit ratio	1.7
Government-bonds-to-deposits ratio	25.4%
Ratio of private consumption and investment to GDP	97%
Ratio of government consumption to GDP	22%
Ratio of imports to GDP	49%
Ratio of exports to GDP	30%
Ratio of loans to total consumption	28%
Ratio of bonds to total consumption	4%

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