R.E.M. 2.0
An estimated DSGE model for Romania

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Abstract

This paper describes the theoretical structure and estimation results for a DSGE model for the Romanian economy. Having as benchmark the model of Christiano et al. (2011), the additional features we introduce refer to partial euroization in the financial sector, oil as an input in production process, dis-aggregation of headline inflation into administered and core components, National Accounts consistent measures for GDP volume and deflator, and an extension of the foreign sector to a two country semi-structural model. The model is estimated using a relatively short dataset, subject to potential revisions and characterized by high uncertainty and volatility. Its evaluation is performed using a wide range of procedures, like impulse response functions, measures of data fit, variance and historical decompositions, forecasting performance. The results highlight the significance of the added mechanisms in explaining the Romanian business cycle over the analyzed period, confirming also the overall ability of the model to supply theoretically and data coherent policy analysis.

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Contents

1 Introduction

In this paper we describe a DSGE model with the theoretical structure tailored and implemented for Romania (R.E.M. 2.0 - Romania's Economic Model). The model is built on the usual new Keynesian small open economy framework, incorporating standard features used in this literature, such as monopolistic competition and price rigidities, working capital channel, investment adjustment costs, variable capital utilization and habit in consumption. In the initial stage, the model drew heavily upon the work of Christiano et al. (2011), which incorporate in the framework mentioned before both financial frictions in the form of a financial accelerator along the lines of Bernanke et al. (1999), and labor market frictions in the spirit of the search and matching theory. As for the empirical part, we have as benchmark the work of Copaciu (2012), which estimated the models in Christiano et al. (2011) for Romania. Furthermore, the model was enriched along several dimensions, in order to account for the specific features of the Romanian economy, and at the same time to satisfy the requirements of regular forecasting exercises in the context of the inflation targeting regime in place.

To accommodate the existence of a significant share of foreign currency (EUR) denominated loans in the local economy (approximately 45% for new loans to non-financial corporations), the financial sector of the model was adapted by introducing two types of entrepreneurs, according to the currency in which they borrow. As the entrepreneurs are now exposed to exchange rate risk, *this extension gives rise to balance sheet effects* in the model, such that a depreciation of the domestic currency has also a negative influence on output, apart from a positive impact through the net exports channel. Although we introduced two types of banks to match the demand of funds depending on the currency they are denominated, there is no currency mismatch in their balance sheets, as the exchange rate risk is entirely transferred to entrepreneurs, in line with the empirical evidence for Romania. Last but not least, we calibrate the share of entrepreneurs borrowing in foreign currency (FC) relative to those borrowing funds denominated in domestic currency (DC) by matching the empirical ratio of foreign to domestic currency denominated loans demanded by non-financial corporations operating in Romania over the analyzed period (2005-2014).

The production sector of the model was modified to include the use of (imported) oil as an input for intermediate goods. The movements in global oil prices (set in US dollars) are reflected only partially in the price of oil in the domestic market (incomplete pass-through), owing to the adoption of local currency pricing hypothesis, price rigidity and monopolistic competition.

The production sector was further adapted to account for the presence of a significant share of goods and services with administered prices in the CPI basket (approximately one fifth), following the approach of de Castro et al. (2011). Given that the behavior of these prices is related to the real marginal costs developments to a lesser degree, there is a risk of obtaining misleading results without modeling these prices explicitly, when estimating the model or using it for analysis and forecasts. Excluding the administered prices from the CPI basket is likely to offer a more relevant measure of the underlying inflationary pressures, needed in the monetary policy decision process. Technically, the administered prices were introduced in the model by assuming that a fraction of the consumption goods producers are not allowed to optimize their prices, but instead must follow some exogenous indexation rule.

In addition to oil as a new type of import, the external dimension of the model was modified by modeling the rest of the foreign sector as a two country (Euro area and US/Rest of the world) open economies new Keynesian semi-structural model, matching the currency structure of the Romanian foreign trade in goods and services. Given that the foreign currency financial transactions take place only in EUR, *external shocks have different effects on the domestic economy, according to the originating country.*

When taking the model to the data, a number of issues were considered. First, to reconcile the specific growth rates of the observed variables with the balanced growth path of the model, we follow the approach of Argov et al. (2012) for model consistent filtering (section 3). Second, we define the GDP volume and deflator in a manner consistent with the National Accounts measure (section 2.9). Moreover, when estimating the model, we use an endogenous prior approach as proposed by Christiano et al. (2011), but we modify it in order to allow matching certain moments only for a subset of variables. Last but not least, we estimate the external sector outside the main model, using also an endogenous prior procedure and model consistent filtering a la Argov et al. (2012).

When estimating the model we used a total of 29 observed series covering 2005Q3:2014Q3 observations. The limited sample is motivated by some issues generally specific to emerging economies, like data availability, structural breaks, or monetary policy regime changes. The block modeling the two foreign economies was estimated exogenously using 8 series and covering a longer sample. Part of the coefficients were calibrated because of identification issues or in order to match certain targets consistent with the data (like investment to output ratio or the ratio of foreign to domestic loans). The remaining parameters were estimated in a Bayesian framework, augmented with the endogenous priors procedure developed by Christiano et al. (2011).

The model evaluation toolkit consists of various standard procedures that were performed using posterior means of the estimated parameters. Impulse response functions revealed the importance of the currency substitution, balance sheet and wealth effects, captured when modeling two distinct types of entrepreneurs (defined with respect to the currency they borrow in). Accordingly, the currency denomination of foreign financial flows (EUR in our case) and the degree of euroization (the relative shares of the two types of entrepreneurs) matter for the reaction of sector specific and aggregate endogenous variables.

The estimated DSGE model was able to efficiently match first and second order moments as displayed by the data. This outcome was favored by the technical approaches implemented when estimating the model: the excess trends as in Argov et al. (2012) allowed to perfectly match the means, while the endogenous priors as in Christiano et al. (2011) improved the matching of standard deviations. Also, some unobserved variables retrieved by the Kalman smoother fit quite well the dynamics of their data counterparts, like bankruptcy rates, number of vacant jobs or the risk premium (as proxied by credit default swap or option adjusted spread).

Variance decomposition analysis at relevant monetary policy horizons (8 quarters) revealed the high contributions of shocks originating in the financial sector (risk premium and two entrepreneurial net worth innovations) and importers-exporters sector (markups affecting exporters and imports for exports producers). These results highlight the importance of both financial frictions and open economy dimensions of the model. At the same time, the effects of labor market frictions appeared to be of little significance. The historical decomposition of endogenous variables into individual contributions of structural shocks during the analyzed period offered relevant conclusions regarding the importance of particular innovations during specific quarters. Demand side shocks appeared as important sources of output and private consumption dynamics, while financial sector (risk premium included) related shocks explain much of the fluctuations in investment, interest rate spreads and exchange rate. Openness related variables (imports, exports, current account) appeared to be driven by specific markup shocks, and also by innovations in the risk premium.

The in-sample (univariate and multivariate) forecasting accuracy of the estimated DSGE model compares well with simple univariate methods (like random walk and auto-regressions), but is generally dominated by the Bayesian VAR models predictions.

We also made an attempt at simulating a more complex scenario that would match the expected near term monetary policy developments in Euro area and the US. Namely, we analyzed the reaction of endogenous variables to a simultaneous increase in the US and a decrease in the Euro area interest rates, for different levels of euroization. As mentioned before, changes in the external sector variables affect the domestic economy through different channels. While a shock originating in the US economy directly influences domestic variables via the net exports channel, a shock to the Euro area economy has an additional direct impact through the balance sheet channel, given EUR denomination of foreign currency loans. Moreover, the importance of the latter mentioned mechanism depends positively on the euroization degree of the domestic economy. Therefore, the increase in investment following the decrease in the EURIBOR interest rate leads to a stronger increase in output when euroization is higher. If the foreign currency loans had been denominated in USD, the increase in the US interest rate would have led to a stronger decline in output in the more dollarized economy.

2 The model

The theoretical model is an extension of Christiano et al. (2011) allowing additionally for: oil as an input in the production of domestic goods, domestic and foreign currency borrowing in the case of entrepreneurs, the dis-aggregation of consumer prices into CORE1 and administered components and an extended, two regions, external sector. In presenting the model in the following subsections, when necessary, we will follow closely Christiano et al. (2011).

2.1 Structure of the model - overview

The structure of the model is presented in figure 1. **The production sector** consists of intermediate goods producers, capital goods producers, importers and final goods producers.

Domestic intermediate goods retailer aggregates the supply of such goods received from a continuum of producers operating in a monopolistic competition environment. Any of the latter uses a production function that combines imported oil, capital services (provided by the entrepreneurs borrowing funds denominated in domestic and foreign currency respectively) and labor, with the combination of the last two representing the value added (VA) in the economy. In the production of intermediate goods, permanent and temporary technology shocks affect productivity. **The importing sector** comprises of four types of importers that buy a homogeneous good from foreign markets and differentiate it into consumption, investment, export goods and oil.

For each of the above mentioned categories, inflation evolution is described by a new Keynesian Phillips curve, resulting from the assumptions of Dixit-Stiglitz competitive monopolistic framework and (local currency) nominal price stickiness, with markup shocks affecting marginal costs. Furthermore, for each category, except oil importers, a working capital channel is present (i.e. firms finance in advance part of their production costs by intra-period loans). Thus, besides foreign inflation and oil price shocks, there is also an impact of interest rates[1] on firms' marginal cost.

The domestic intermediate and the imported goods are used in the next stage by **the producers of final goods** (using constant elasticity of substitution production functions), resulting in final consumption (CORE1 and administered prices goods), investment, export and government goods. The only exception is represented by oil goods, which, as mentioned above, are being used in the production of domestic intermediate goods only. The demand for final goods comes: from households for final consumption goods, from the fiscal authority for final government goods, from capital producers for investment goods, while exports are demanded from abroad.

As opposed to foreign currency financial transactions that take place only in EUR, external trade with goods and services takes place both in EUR and USD, as they are the currencies used in the invoicing of more than 90% of international trade transactions having a Romanian entity as counterpart. The external demand for domestic goods faced by exporters is also influenced by foreign demand shocks.

[1]Domestic interest rate for the producers of domestic intermediate goods and foreign interest rate for importers.

Households buy the consumption goods from final goods producers and supply labor services to the domestic intermediate goods producers. The saving process consists of bank deposits in domestic and foreign currency. When maximizing their utility, households face habit in consumption, with consumption preference and labor disutility shocks influencing their optimal decisions. In supplying labor services, households face employment frictions with its' members alternating between being employed or not. Adding employment frictions to the model is done in order to capture both the extensive and the intensive margins of labor supply, as data points towards variation in total hours worked as coming from variations in both margins. As in Christiano et al. (2011), when employed, workers separate from their employer either exogenously or endogenously (i.e. if their individual productivity is below a certain, endogenously determined, cutoff), while when unemployed they do undirected search. Wages are renegociated periodically through atomistic Nash bargaining. The decisions of agents in the presence of employment frictions is also influenced by shocks to the bargaining power of workers, to the matching productivity and to the dispersion of productivity among workers.

The investment goods producers meet the demand of capital goods producers, with the relative price of investment goods being influenced by an investment specific permanent technology shock. **Capital producers** use investment goods to add to the previous stock of (undepreciated) capital, before supplying the new capital towards entrepreneurs. When transforming investment into capital, they face investment adjustment costs, while their optimal choice is influenced by marginal efficiency of investment shocks.

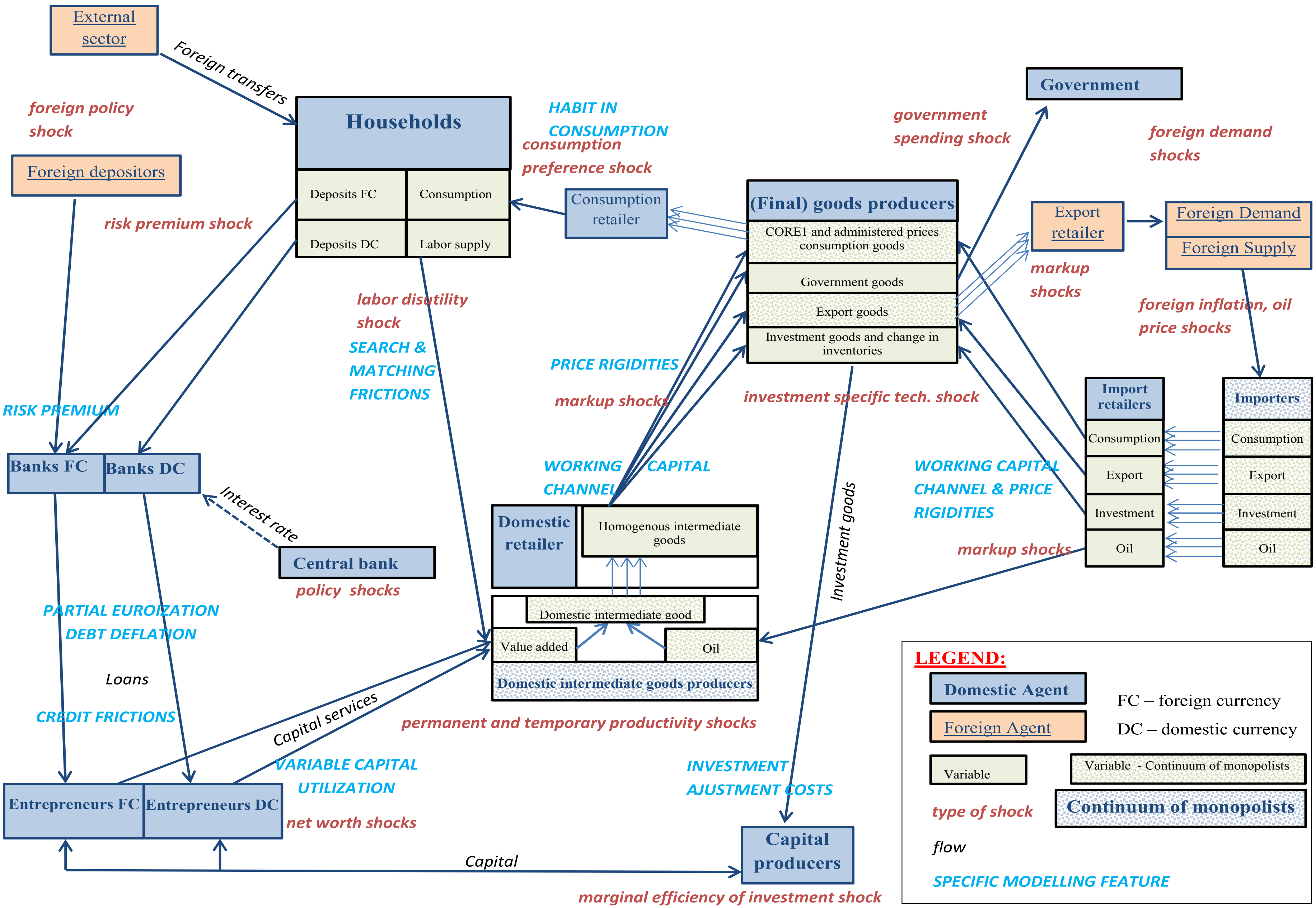
The entrepreneurs buy capital from capital producers, set its utilization rate and rent capital services to intermediate goods producers. Entrepreneurs access loans to cover the part of the acquisition cost of capital that remains after self-financing occurs. Financial frictions between entrepreneurs and banks arise in the model given the presence of asymmetric information and costly state verification. There are two types of entrepreneurs, financing themselves by borrowing either in foreign currency (EUR in our case) or in domestic currency. The presence of foreign currency lending gives rise to balance sheet effects. The optimal choice of entrepreneurs is also influenced by two shocks specific to this sector: a shock to the net worth of entrepreneurs and one that impacts on their idiosyncratic productivity (i.e. "risk shocks").

Lending to the entrepreneurs takes place through **banks**. There are two types of banks: one that deals with entrepreneurs borrowing in domestic currency and one that provides funds for those borrowing in foreign currency. The sources of these funds are represented by deposits, with domestic currency deposits being provided by domestic households, while foreign currency funds come from both domestic households and abroad. For the latter category of funds a premium, influenced also by exogenous shocks, is paid over the corresponding external interest rate.

The central bank sets the domestic monetary policy rate according to a Taylor rule. **The fiscal authority** collects taxes, demands government goods from the corresponding producers and uses lump sum transfers towards households to keep the budget balanced.

We model **the foreign sector** as a two country (Euro area and US) open economies new Keynesian semi-structural model, with the price of oil in USD included, as an exogenous process.

Figure 1: *Structure of the model*



2.2 Production sector

Domestic intermediate goods, produced using capital services (provided by entrepreneurs borrowing in domestic and foreign currencies), labor supplied by households and imported oil, are combined with different imported inputs, other than oil, in order to produce (private and government) consumption, investment and export goods demanded by households, government, capital producers and foreign export retailers. A Dixit-Stiglitz competitive monopolistic framework is used in order to introduce price stickiness for imported, intermediate domestic, consumption and exported goods.

2.2.1 Domestic producers

A representative firm, operating in a perfectly competitive environment, taking the price of output (P_t) and inputs ($P_{i,t}$) as given, combine imperfectly substitutable domestic goods[2] into a homogeneous good using the following constant elasticity of substitution technology:

$$Y_t = \left[\int_0^1 {Y_{i,t}}^{\frac{1}{\lambda_d}} di \right]^{\lambda_d} \tag{1}$$

where $1 \leq \lambda_d < \infty$ is the markup in the domestic goods market. The profit maximization problem of the representative, domestic goods aggregating (retailer) firm is:

$$\max_{Y_{i,t}} \ \Pi_t^Y = P_t Y_t - \int_0^1 P_{i,t} Y_{i,t} di \tag{2}$$

Solving the above problem results in the following demand schedule for any individual domestic intermediate good i:

$$Y_{i,t} = \left(\frac{P_t}{P_{i,t}} \right)^{\frac{\lambda_d}{\lambda_d - 1}} Y_t \tag{3}$$

where Y_t is a shifter in the demand for $Y_{i,t}$. Given the demand equation derived above and perfect competition in the final good market, the resulting relation between the aggregate price index of the retailer and the prices of individual domestic goods is:

$$P_t = \left[\int_0^1 P_{i,t}^{\frac{1}{1-\lambda_d}} di \right]^{(1-\lambda_d)} \tag{4}$$

Each differentiated intermediate good is produced by monopolistic competitive firms, indexed by $i \in [0, 1]$, using the following technology:

$$Y_{i,t} = \left((1-\omega_o)^{\frac{1}{\eta_o}} VA_{i,t}^{\frac{\eta_o - 1}{\eta_o}} + \omega_o^{\frac{1}{\eta_o}} \left(Oil_{i,t}^m \right)^{\frac{\eta_o - 1}{\eta_o}} \right)^{\frac{\eta_o}{\eta_o - 1}} - z_t^+ \phi \tag{5}$$

with:

$$VA_{i,t} = \epsilon_t (z_t H_{i,t})^{1-\alpha} (K_{i,t})^{\alpha} \tag{6}$$

[2]For simplicity, we will continue to refer to this type of goods as domestic (intermediate) goods, although imported oil and part of the capital that is financed by loans in foreign currency are used in its production.

and

$$K_{i,t} = \left[(\omega_k)^{1/\eta_k} \left(K_{i,t}^{DC} \right)^{\frac{\eta_k - 1}{\eta_k}} + (1-\omega_k)^{1/\eta_k} \left(K_{i,t}^{FC} \right)^{\frac{\eta_k - 1}{\eta_k}} \right]^{\frac{\eta_k}{\eta_k - 1}} \tag{7}$$

where:

- $VA_{i,t}$ is value added in the economy having a $(1-\omega_o)$ share in gross output $Y_{i,t}$;
- $Oil_{i,t}^m$ is imported oil entering the production of domestic intermediate good with share ω_o;
- η_o is the elasticity of substitution between imported oil and value added;
- $H_{i,t}$ represent homogeneous labor services used by firm i, with share $(1-\alpha) \in (0,1)$ in total value added;
- $K_{i,t}$ are aggregate capital services rented from entrepreneurs having a share $\alpha \in (0,1)$ in value added;
  - $K_{i,t}^{DC}$ are capital services rented from entrepreneurs borrowing in domestic currency (DC), with $\omega_k \in (0,1)$ representing their mass in the production of aggregate capital services;
  - $K_{i,t}^{FC}$ are capital services rented from entrepreneurs borrowing in foreign currency (FC), with $1-\omega_k \in (0,1)$ representing their mass in the production of aggregate capital services;
  - η_k represents the elasticity of substitution between capital services categories[3];
- ϵ_t is a stationary productivity shock;
- z_t^+ is the aggregate technology shock, representing a combination of investment (ψ_t) and neutral unit-root (z_t) technology shocks $\left(z_t^+ = z_t \left(\psi_t \right)^{\frac{\alpha}{1-\alpha}} \right)$;
- ϕ is a fixed cost that grows with the aggregate technology rate and makes possible to impose zero profits in steady state, hence being consistent with the no entry or exit assumptions.

Any individual intermediate goods producer acts competitively on factor markets, solving the following cost minimization problem:

$$\min_{K_{i,t}^{DC}, K_{i,t}^{FC}, H_{i,t}, Oil_{i,t}^m} W_t R_t^f H_{i,t} + \left(r_t^{DC,k} P_{i,t} \right) K_{i,t}^{DC} + \left(r_t^{FC,k} P_{i,t} \right) K_{i,t}^{FC} + P_t^{m,oil} Oil_{i,t}^m \tag{8}$$

subject to (5), (6) and (7), where:

[3] Since all entrepreneurs are identical $K_{i,t}^{DC} = \omega_k K_{i,t}^{DC,entrep.}$ and $K_{i,t}^{FC} = (1-\omega_k) K_{i,t}^{FC,entrep.}$.

- $W_t R_t^f H_{i,t}$ represent the labor costs of the firm adjusted in this case by R_t^f that reflects the presence of a working capital channel, in which firms finance in advance part of their wage bill by loans, with $R_t^f = \nu^f R_t + 1 - \nu^f$ where R_t is the gross nominal interest rate and ν^f is the proportion of the wage bill that is financed in advance[4];

- $R_t^{j,k} K_{i,t}^j$ are the costs with the rented capital services, with $r_t^{j,k}$ being the associated gross nominal rental rate scaled by $P_{i,t}$, where $j \in \{DC, FC\}$;

- $P_t^{m,oil} Oil_{i,t}^m$ is the cost with oil input.

The first order conditions associated with the above optimization problem are:

$$H_{i,t} : W_t R_t^f = (1-\alpha) mc_t P_{i,t} \frac{VA_{i,t}}{H_{i,t}} \left[\frac{(1-\omega_o)\left((1-\omega_o)^{\frac{1}{\eta_o}} VA_{i,t}^{\frac{\eta_o - 1}{\eta_o}} + \omega_o^{\frac{1}{\eta_o}} \left(Oil_{i,t}^m\right)^{\frac{\eta_o-1}{\eta_o}} \right)^{\frac{\eta_o}{\eta_o-1}}}{VA_{i,t}} \right]^{\frac{1}{\eta_o}} \tag{9}$$

$$K_{i,t}^{DC} : r_t^{DC,k} = \alpha mc_t \frac{VA_{i,t}}{K_{i,t}} \left(\frac{\omega_k K_{i,t}}{K_{i,t}^{DC}} \right)^{\frac{1}{\eta_k}} \left[\frac{(1-\omega_o)\left((1-\omega_o)^{\frac{1}{\eta_o}} VA_{i,t}^{\frac{\eta_o - 1}{\eta_o}} + \omega_o^{\frac{1}{\eta_o}} \left(Oil_{i,t}^m\right)^{\frac{\eta_o-1}{\eta_o}} \right)^{\frac{\eta_o}{\eta_o-1}}}{VA_{i,t}} \right]^{\frac{1}{\eta_o}} \tag{10}$$

$$K_{i,t}^{FC} : r_t^{FC,k} = \alpha mc_t \frac{VA_{i,t}}{K_{i,t}} \left(\frac{(1-\omega_k) K_{i,t}}{K_{i,t}^{FC}} \right)^{\frac{1}{\eta_k}} \left[\frac{(1-\omega_o)\left((1-\omega_o)^{\frac{1}{\eta_o}} VA_{i,t}^{\frac{\eta_o - 1}{\eta_o}} + \omega_o^{\frac{1}{\eta_o}} \left(Oil_{i,t}^m\right)^{\frac{\eta_o-1}{\eta_o}} \right)^{\frac{\eta_o}{\eta_o-1}}}{VA_{i,t}} \right]^{\frac{1}{\eta_o}} \tag{11}$$

$$Oil_{i,t}^m : \frac{P_t^{m,oil}}{P_{i,t}} = mc_t \left[\frac{\omega_o \left((1-\omega_o)^{\frac{1}{\eta_o}} VA_{i,t}^{\frac{\eta_o - 1}{\eta_o}} + \omega_o^{\frac{1}{\eta_o}} \left(Oil_{i,t}^m\right)^{\frac{\eta_o-1}{\eta_o}} \right)^{\frac{\eta_o}{\eta_o-1}}}{Oil_{i,t}^m} \right]^{\frac{1}{\eta_o}} \tag{12}$$

plus the production function (5) associated with the FOC with respect to the Lagrange multiplier.

In the above expressions, mc_t represents the real marginal cost (whereas $mc_t P_{i,t}$ is the nominal marginal cost and also the associated Lagrange multiplier). Solving the above equations for mc_t yields:

$$mc_t = \frac{\tau_t^d}{P_{i,t}} \left[(1-\omega_o) \left(P_{i,t}^{VA}\right)^{1-\eta_o} + (\omega_o) \left(P_{i,t}^{m,oil}\right)^{1-\eta_o} \right]^{\frac{1}{1-\eta_o}} \tag{13}$$

[4]Similar with Christiano et al. (2005), the presence of the working capital channel is necessary to accommodate the empirical evidence according to which prices may rise after a hike in the monetary policy rate given that firms finance part of their variable inputs by short term loans.

where $P_{i,t}^{VA}$ is defined as:

$$\frac{P_{i,t}^{VA}}{P_{i,t}} \equiv \left(\frac{W_t R_t^f}{(1-\alpha) P_{i,t} z_t}\right)^{1-\alpha} \left(\frac{\left[\omega_k \left(r_t^{DC,k}\right)^{1-\eta_k} + (1-\omega_k)\left(r_t^{FC,k}\right)^{1-\eta_k}\right]^{\frac{1}{1-\eta_k}}}{\alpha}\right)^{\alpha} \frac{1}{\epsilon_t} \tag{14}$$

where, as Christiano et al. (2011) point out, τ_t^d acts like a tax shock (markup shock in the linearized version of the model) that is not present in the production function.

Each firm exercises monopolistic power over its product, given the demand coming from the aggregating firm. Price setting at firm level is modeled in a time dependent fashion *à la* Calvo. Therefore, with probability $1-\xi_d$, each firm can reoptimize its price, with the implied duration of price quotation being $\frac{1}{1-\xi_d}$. With complementary probability ξ_d firms cannot reoptimize and index their price to a combination of last period inflation and current central bank's inflation target given by:

$$P_{i,t} \equiv (\pi_{t-1})^{\kappa_d} (\bar{\pi}_t^c)^{1-\kappa_d} P_{i,t-1} \tag{15}$$

where κ_d measures the degree of indexation to last period inflation (π_{t-1}), with the complementary probability reflecting the indexation to the current inflation target $(\bar{\pi}_t^c)$.

Firms that reoptimize their prices choose the new price to maximize the present discounted value of profits, that is:

$$E_t \sum_{j=0}^{\infty} \beta^j \upsilon_{t+j} [P_{i,t+j} Y_{i,t+j} - mc_{t+j} P_{t+j} Y_{i,t+j}] \tag{16}$$

subject to the demand given by (3), where υ_{t+j} is the Lagrange multiplier from household's optimization problem, reflecting their ownership of firms[5].

Domestic homogeneous goods are used in the production of government, consumption, investment and export goods. An important note should be made here: in a model without oil entering the production of domestic intermediate goods, Y_t is usually considered as a proxy for the gross domestic product. In our case, VA_t represents the gross value added, while a national accounts consistent definition of GDP is presented in section 2.9.2.

2.2.2 Importers

Importing sector comprises of four types of firms that buy a homogeneous good from foreign markets and differentiate it into consumption goods, $C_{i,t}^m$, investment goods to be finally used by capital producers, $I_{i,t}^m$, and export goods, $X_{i,t}^m$, before monopolistically supplying them to the corresponding retailers, with the latter operating in a perfectly competitive environment. As for imported oil goods, $Oil_{i,t}^m$, used in the final stage by the intermediate domestic goods producers, the price of the homogenous good is set in USD. We describe the problem generically for a firm belonging to category Θ, where $\Theta \in \{C, I, X, Oil\}$.

[5]The detailed derivation of the price setting problem and the associated first order conditions are presented in the Appendix of Christiano et al. (2011).

Again, the production function of the domestic retailer of imported goods that operates in a perfectly competitive environment is shown in (17), with the demand schedule for any individual imported good i resulting from the profit maximization problem being given by (18).

$$\Theta_t^m = \left[\int_0^1 \left(\Theta_{i,t}^m\right)^{\frac{1}{\lambda_{m,\Theta}}} di \right]^{\lambda_{m,\Theta}} \tag{17}$$

$$\Theta_{i,t}^m = \Theta_t^m \left(\frac{P_t^{m,\Theta}}{P_{i,t}^{m,\Theta}} \right)^{\frac{\lambda_{m,\Theta}}{\lambda_{m,\Theta}-1}} \tag{18}$$

The associated marginal cost for the individual firm importing quantity $\Theta_{i,t}^m$ is:

$$NMC_t^{m,\Theta} = \tau_t^{m,\Theta} S_t^{ef} P_t^* R_t^{\nu,*} \tag{19}$$

where $\tau_t^{m,\Theta}$ behaves again like a markup shock that does not appear in the production function; S_t^{ef} is the effective[6] nominal exchange rate; P_t^* is the effective foreign price level and $R_t^{\nu}, *$represents the effective nominal interest rate paid by firms given the presence of a working capital channel. The expression for $R_t^{\nu}, *$ is given by:

$$R_t^{\nu,*} = \nu^* R_t^* + 1 - \nu^* \tag{20}$$

where R_t^* is the effective foreign nominal interest rate and ν^* is the proportion of inputs that is financed in advance by loans taken in foreign currency. For oil imported products, ν^* is assumed to be zero, while the external price is set in US dollars. Thus, the associated individual marginal cost is given by:

$$NMC_t^{m,oil} = \tau_t^{m,oil} S_t^{RON/USD} P_t^{oil,usd} \tag{21}$$

Total value of imports for firms belonging to category Θ_t is:

$$S_t^{ef} P_t^* R_t^{\nu,*} \Theta_t^m \tag{22}$$

with the similar quantity for oil being defined as:

$$S_t^{RON/USD} P_t^{oil,usd} Oil_t^m \tag{23}$$

The price setting problems of the importing firms are similar with that of the intermediate goods producers. Consequently, each firm producing good $\Theta_{i,t}^m$ exercise monopolistic power over its product, given the demand coming from the domestic retailer of imported goods. Firms that cannot reoptimize their price, index it to a combination of last period inflation and current central bank's inflation target given by:

$$P_{i,t}^{m,\Theta} \equiv \left(\pi_{t-1}^{m,\Theta}\right)^{\kappa_{m,\Theta}} \left(\bar{\pi}_t^c\right)^{1-\kappa_{m,\Theta}} P_{i,t-1}^{m,\Theta} \tag{24}$$

[6]Effective variables are a combination of EUR and USD related variables, as defined in section 2.8.

where $\kappa_{m,\Theta}$ measures the degree of indexation to last period inflation $\left(\pi_{t-1}^{m,\Theta}\right)$, with the complementary probability reflecting the indexation to the inflation target $(\bar{\pi}_t^c)$.

With probability $1-\xi_{m,\Theta}$, each firm can reoptimize its price in order to maximize the present discounted value of profits, that is:

$$E_t \sum_{j=0}^{\infty} \beta^j \upsilon_{t+j} [P_{i,t+j}^{m,\Theta} \Theta_{i,t+j}^m - \tau_{t+j}^{m,\Theta} S_{t+j}^{ef} P_{t+j}^* R_{t+j}^{\nu,*} \Theta_{i,t+j}^m] \tag{25}$$

subject to the demand given by (18), where υ_{t+j} is the Lagrange multiplier from household's optimization problem, reflecting their ownership of firms. The first order conditions associated with the price setting problem are presented in the Appendix of Christiano et al. (2011). Again, whenever the case, for oil the problem should take into account that the foreign currency price is in US dollars and no working capital channel is assumed.

A note should be made regarding the currency in which import or export prices are set. The approach presented here assumes, both for exports and imports, *local currency pricing* (i.e. prices are set in the currency of the country where goods are consumed) instead of *producer currency pricing* (i.e. prices are set in the currency of the producer). This approach, together with price rigidity in a monopolistic environment, generates an imperfect pass-through of (present and expected) exchange rate changes in export and import prices, with more rigid prices resulting in a lower pass-through of exchange rate variations, through the impact on marginal cost, on import and export prices inflation[7].

Except the oil imported products that are used as inputs in the production of domestic intermediate goods as described in section 2.2.1, the next stage of the production process implies assembling domestic homogeneous and imported goods from retailers into final goods. This is done by perfectly competitive firms operating in the investment sector. The supply of final goods meets the demand coming from capital goods producers. As for the consumption and export imported goods, these are supplied by retailers to a continuum of final goods producers, as described in the following sections.

2.2.3 Consumption goods producers

In constructing the consumption goods sector, we depart from Christiano et al. (2011) by introducing two stages of production, whereas in their setup the final consumption was produced by a representative competitive firm that combined homogenous domestic intermediate goods and homogenous imported consumption goods using CES technology[8]. We adapted the framework, following closely de Castro et al. (2011), in order to account for a feature of the Romanian economy, namely the existence of a relatively high share of goods and services with administered prices in the CPI basket. These include electricity, natural gas, heating, some pharmaceutical products and account for approximately a fifth of the CPI basket. Romania agreed with the European Commission to gradually deregulate prices

[7]Although empirically prices are more rigid in developed economies compared with emerging ones, Zorzi et al. (2007) do not find significant differences regarding exchange rate pass-through on import and consumer prices between these groups of countries.

[8]The two stages of production are present also in Christiano et al. (2011) for the export sector, as explained in section 2.2.6.

for electricity and natural gas in the coming years. Therefore, the calendars for deregulation provide valuable information with respect to the future evolution of administered prices. The introduction of the administered prices provides also a technical advantage when using the model for forecasting, by allowing the forecast to be conditioned on the information from the deregulation calendars.

In the first stage of production, a continuum of producers indexed by $i \in [0,1]$ combine homogenous domestic intermediate goods and homogenous imported consumption goods using CES technology, resulting in a range of differentiated consumption goods $C_{i,t}$:

$$C_{i,t} = \left\{ (1-\omega_c)^{1/\eta_c} \left(C_{i,t}^{d} \right)^{\frac{\eta_c}{\eta_c - 1}} + (\omega_c)^{1/\eta_c} \left(C_{i,t}^{m} \right)^{\frac{\eta_c}{\eta_c - 1}} \right\}^{\frac{\eta_c - 1}{\eta_c}} \tag{26}$$

where ω_c is the share of imported consumption goods ($C_{i,t}^{m}$), and η_c is the elasticity of substitution between input goods. The cost minimization problem gives the demands for inputs as follows:

$$C_{i,t}^{d} = (1-\omega_c) \left(\frac{NMC_t^c}{P_t} \right)^{\eta_c} C_{i,t} \tag{27}$$

$$C_{i,t}^{m} = (\omega_c) \left(\frac{NMC_t^c}{P_t^{m,c}} \right)^{\eta_c} C_{i,t} \tag{28}$$

Again, NMC_t^c is the nominal marginal cost, with the real one being given by:

$$mc_t^c = \frac{NMC_t^c}{P_t^c} = \frac{\left\{ (1-\omega_c) P_t^{1-\eta_c} + (\omega_c) \left(P_t^{m,c} \right)^{1-\eta_c} \right\}^{\frac{1}{1-\eta_c}}}{P_t^c} \tag{29}$$

In the second stage, the final consumption goods C_t are produced by a representative, competitive retailer using the differentiated consumption goods $C_{i,t}$:

$$C_t = \left[\int_0^1 \left(C_{i,t} \right)^{\frac{1}{\lambda_c}} di \right]^{\lambda_c} \tag{30}$$

The optimization problem of the retailer yields the demand function for individual consumption goods and the consumption price:

$$C_{i,t} = \left(\frac{P_{i,t}^c}{P_t^c} \right)^{-\frac{\lambda_c}{\lambda_c - 1}} C_t \tag{31}$$

$$P_t^c = \left[\int_0^1 \left(P_{i,t}^c \right)^{\frac{1}{1-\lambda_c}} di \right]^{(1-\lambda_c)} \tag{32}$$

With the aim of taking into account the existence of administered prices, we follow de Castro et al. (2011) and consider two types of individual consumption goods producers, with fractions ω_{adm} and $(1-\omega_{adm})$, *differing only with respect to their price setting behavior.* Following the NBR terminology, we refer to the non-administered prices as CORE1 prices, having a $(1-\omega_{adm})$ weight in the CPI basket, and to their producers as CORE1 producers, *indexed by* $i \in [\omega_{adm}, 1]$. They exercise monopolistic power over their product, given the demand coming from the retailer.

We model their price setting process *à la* Calvo, with ξ_c representing the probability that firms cannot reoptimize their prices. In this latter case, each producer $i \in [\omega_{adm}, 1]$ indexes its last period price ($P^{core1}_{i,t-1}$) by a weighted average of last period inflation (π^c_{t-1}) and current central bank's inflation target given by:

$$P^{core1}_{i,t} \equiv \left(\pi^c_{t-1}\right)^{\kappa_c} \left(\overline{\pi}^c_t\right)^{1-\kappa_c} P^{core1}_{i,t-1} \tag{33}$$

Each firm that has the possibility to reset their price chose it so as to maximize the present discounted value of its profits, given by:

$$E_t \sum_{j=0}^{\infty} \beta^j \upsilon_{t+j} [P^{core1}_{i,t+j} - NMC^c_{t+j}] C_{i,t+j} \tag{34}$$

subject to the demand given by (31), where υ_{t+j} is the Lagrange multiplier from household's optimization problem, reflecting their ownership of firms. The first order conditions associated with the price setting problem are analogous to the ones for domestic intermediate and imported goods price setting problems.

Similar to the setup in de Castro et al. (2011), the ω_{adm} fraction of consumption good producers, indexed by $i \in [0, \omega_{adm}]$, are unable to chose their prices optimally, but follow an exogenous pricing policy. In each period, with probability ξ_{adm}, firms with administered prices index their price with the current central bank inflation target:

$$P^{adm}_{i,t} \equiv \overline{\pi}^c_t P^{adm}_{i,t-1} \tag{35}$$

whereas with complementary probability $1-\xi_{adm}$ they are allowed to index their prices with the following indexation factor:

$$\Upsilon^{adm}_t \equiv (\overline{\pi}^c)^{1-4\chi_{adm}} \left[\pi 4_t \left(\frac{q_{t-1}}{q_{t-5}}\right)^{v^1_{adm}} \left(\frac{mc^c_{t-1}}{mc^c_{t-5}}\right)^{v^2_{adm}} \right]^{\chi_{adm}} \left(\frac{p^{core1}_t}{p^c_t}\right)^{1-\chi_{adm}} \left(Z^{adm}_t\right)^{\frac{1}{1-\xi_{adm}}} \tag{36}$$

where $\pi 4_t = \prod_{j=1}^{4} \pi^c_{t-j}$ is the annual inflation rate, q_{t-1}/q_{t-5} is the annual change in real effective exchange rate, mc^c_{t-1}/mc^c_{t-5} is the annual change in the real marginal cost of consumption goods producers, p^{core1}_t/p^c_t is the relative price of CORE1 goods to consumption goods price. Z^{adm}_t is an $AR(1)$ process, accounting for unexpected shifts in administered prices, while $\chi_{adm}, v^1_{adm}, v^2_{adm}$ are parameters governing the indexation rule. The specification of the rule is intended to capture the backward-looking nature of the administered price dynamics, while at the same time allowing for influence from the real exchange rate and the real marginal cost.

The administered price index is defined as:

$$P^{adm}_t \equiv \left(\frac{1}{\omega_{adm}} \int_0^{\omega_{adm}} \left(P^c_{i,t}\right)^{\frac{1}{1-\lambda_c}} di\right)^{1-\lambda_c} \tag{37}$$

The expression yields further the equation for administered price inflation:

$$\pi_t^{adm} = \left[(1 - \xi_{adm}) \left(\Upsilon_t^{adm} \right)^{\frac{1}{1-\lambda_c}} + \xi_{adm} \left(\overline{\pi}_t^c \right)^{\frac{1}{1-\lambda_c}} \right]^{1-\lambda_c} \tag{38}$$

Given (32), we express overall CPI index as a weighted average of CORE1 index and administered price index:

$$P_t^c = \left[\omega_{adm} \left(P_t^{adm} \right)^{\frac{1}{1-\lambda_c}} + (1 - \omega_{adm}) \left(P_t^{core1} \right)^{\frac{1}{1-\lambda_c}} \right]^{1-\lambda_c} \tag{39}$$

with the corresponding inflation rate being defined as: $\pi_t^c = \frac{P_t^c}{P_{t-1}^c}$, where P_t^{core1} is the aggregate CORE1 price index.

2.2.4 Investment goods producers

The production function of investment goods used by a representative competitive firm is given by:

$$\begin{aligned} & I_t + \Delta INV_t + a^{DC}(u_t^{DC})\omega_k \bar{K}_t^{DC} + a^{FC}(u_t^{FC}) \left(1 - \omega_k\right) \bar{K}_t^{FC} \\ & = \psi_t \left\{ (1 - \omega_i)^{1/\eta_i} \left(I_t^d \right)^{\frac{\eta_i}{\eta_i - 1}} + (\omega_i)^{1/\eta_i} \left(I_t^m \right)^{\frac{\eta_i}{\eta_i - 1}} \right\}^{\frac{\eta_i - 1}{\eta_i}} \end{aligned} \tag{40}$$

with factor demands given by:

$$I_t^d = (1 - \omega_i) \frac{1}{\psi_t} \left(\frac{\psi_t P_t^i}{P_t} \right)^{\eta_i} \left[I_t + \Delta INV_t + a^{DC}(u_t^{DC})\omega_k \bar{K}_t^{DC} + a^{FC}(u_t^{FC}) \left(1 - \omega_k\right) \bar{K}_t^{FC} \right] \tag{41}$$

$$I_t^m = \omega_i \frac{1}{\psi_t} \left(\frac{\psi_t P_t^i}{P_t^{m,i}} \right)^{\eta_i} \left[I_t + \Delta INV_t + a^{DC}(u_t^{DC})\omega_k \bar{K}_t^{DC} + a^{FC}(u_t^{FC}) \left(1 - \omega_k\right) \bar{K}_t^{FC} \right] \tag{42}$$

where: ω_i is the share of imported investment goods; η_i is the elasticity of substitution between input goods.

Total investment, that is, $I_t + \Delta INV_t + a^{DC}(u_t^{DC})\omega_k \bar{K}_t^{DC} + a^{FC}(u_t^{FC}) \left(1 - \omega_k\right) \bar{K}_t^{FC}$, is made of:

- I_t - investment goods purchased to increase the stock of physical capital;
- ΔINV_t - change in inventories;
- ψ_t - an investment specific permanent technology shock;
- $a^{DC}(u_t^{DC})\omega_k \bar{K}_t^{DC} + a^{FC}(u_t^{FC}) \left(1 - \omega_k\right) \bar{K}_t^{FC}$, representing the goods used for physical capital ($\bar{K}_t^{DC}$ and $\bar{K}_t^{FC}$) maintenance.

The introduction of ΔINV_t is motivated by the need to reconcile the model constraints with the national accounts GDP data. It is exogenously determined, by assuming that the share of inventories in I_t, that is $\Delta inv_t = \frac{\Delta INV_t}{I_t}$, follows an AR(1) process.

$$\Delta inv_t = \rho^{\Delta inv} \Delta inv_{t-1} + \left(1 - \rho^{\Delta inv}\right) \Delta inv + \varepsilon_{\Delta inv,t} \tag{43}$$

Christiano et al. (2011) introduce an unit root (with drift) shock, ψ_t, that captures the decline in the relative price of investment goods. In order to have a balanced growth path (in nominal terms), the decline in the relative price of investment needs to have a counterpart given by the assumption that the growth rate of investment in real terms is higher than that of the other (demand defined) GDP components (i.e. $\mu_{z^+,t}$) by exactly the growth rate of ψ_t, that is: $\mu_{\psi,t}$. Also, capital utilization rate, u_t^j, is defined as $u_t^j = \frac{K_t^j}{\bar{K}_t^j}$, whereas $a^j(u_t^j)$ represents the corresponding utilization cost function, as defined in section 2.4, with $j \in \{DC, FC\}$.

Replacing the above factor demands in the production function results in the following relation between prices:

$$P_t^i = \frac{1}{\psi_t} \left\{ (1 - \omega_i) P_t^{1-\eta_i} + (\omega_i) \left(P_t^{m,i}\right)^{1-\eta_i} \right\}^{\frac{1}{1-\eta_i}} \tag{44}$$

with the corresponding inflation rate being defined as: $\pi_t^i = \frac{P_t^i}{P_{t-1}^i}$.

2.2.5 Capital producers

There is a large, fixed number, of identical and competitive capital goods producers. They combine investment goods and old capital in order to produce new installed capital, using the following technology:

$$x^{'} = x + F(I_t, I_{t-1}, \Upsilon_t) = x + \Upsilon_t \left(1 - \tilde{S}\left(\frac{I_t}{I_{t-1}}\right)\right) I_t \tag{45}$$

where Υ_t is a marginal efficiency of investment (MEI) shock as in Justiniano et al. (2011) and $\tilde{S}$ is an investment adjustment costs function as in Christiano et al. (2005). Taking into account that the price of old and new capital is the same given the unit value of the marginal rate of transformation, the time t profits for these producers are:

$$\Pi_t^k = P_t P_{k',t} \left[x + \Upsilon_t \left(1 - \tilde{S}\left(\frac{I_t}{I_{t-1}}\right)\right) I_t \right] - P_t P_{k',t} x - P_t^i I_t \tag{46}$$

Each capital producer solves the following maximization problem:

$$\max_{I_{t+n}, x_{t+n}} E_t \left\{ \sum_{n=0}^{\infty} \beta^n \upsilon_{t+n} \Pi_{t+n}^k \right\} \tag{47}$$

where E_t is the time t conditional expectation, υ_t is the multiplier in household's budget constraint. Setting $x_{t+n} = (1 - \delta) \bar{K}_{t+n}$ in the above maximization problem is consistent with profit maximization (in fact any value of x is profit maximizing) and market clearing, results in the following optimality condition linking the price of installed capital and the price of investment goods:

$$
\begin{aligned}
I_t : \upsilon_t P_t^i + \upsilon_t P_t P_{k',t} \left[-\Upsilon_t \left(1 - \tilde{S}\left(\frac{I_t}{I_{t-1}} \right) \right) + I_t' \tilde{S}' \left(\frac{I_t}{I_{t-1}} \right) \right] \\
-\beta E_t \upsilon_{t+1} P_{t+1} P_{k',t+1} \Upsilon_{t+1} \tilde{S}' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_t}{I_{t-1}} \right)^2 = 0
\end{aligned}
\tag{48}
$$

with the aggregate stock of physical capital evolving according to the following accumulation equation:

$$
\bar{K}_{t+1} = \omega_k \bar{K}_{t+1}^{DC} + (1-\omega_k)\,\bar{K}_{t+1}^{FC} = (1-\delta)\left[\omega_k \bar{K}_t^{DC} + (1-\omega_k)\,\bar{K}_t^{FC}\right] + \Upsilon_t \left(1 - \tilde{S}\left(\frac{I_t}{I_{t-1}} \right) \right) I_t \tag{49}
$$

where $\omega_k \bar{K}_{t+1}^{DC}$ is aggregate physical capital demanded by entrepreneurs borrowing in domestic currency, while $(1-\omega_k)\,\bar{K}_{t+1}^{FC}$ is the similar measure for those entrepreneurs that borrow in foreign currency.

2.2.6 Exporters

Similar to consumption producers, there are two stages in the production of exports. First, monopolistic export producers develop a range of differentiated goods using as inputs domestic goods and imports used in the production of exports. While acting competitively on factor markets, each firm exercise monopolistic power over its product, given the demand coming from the export retailer. Second, the retailer assembles individual export goods $(X_{i,t})$ into a homogeneous export good (X_t), meeting the demand of foreigners. The latter variable is defined as:

$$
X_t = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_f} Y_t^* \tag{50}
$$

where: P_t^* is the effective foreign price index for homogeneous goods; Y_t^* is effective foreign GDP; P_t^x is the effective price index (in foreign currency) of exports and η_f represents the elasticity of foreign demand for domestic exports.

The retailer operates in a perfectly competitive setup, using a Dixit-Stiglitz aggregator given by:

$$
X_t = \left[\int_0^1 (X_{i,t})^{\frac{1}{\lambda_x}} di \right]^{\lambda_x} \tag{51}
$$

with the resulting demand for individual export goods and the export price index being:

$$
X_{i,t} = \left(\frac{P_{i,t}^x}{P_t^x} \right)^{-\frac{\lambda_x}{\lambda_x - 1}} X_t \tag{52}
$$

$$P_t^x = \left[\int_0^1 P_{i,t}^{x \frac{1}{1-\lambda_x}} di \right]^{(1-\lambda_x)} \tag{53}$$

The production function of the i^{th} specialized exporter is given by:

$$X_{i,t} = \left\{ (1-\omega_x)^{1/\eta_x} \left(X_{i,t}^d \right)^{\frac{\eta_x}{\eta_x - 1}} + (\omega_x)^{1/\eta_x} \left(X_{i,t}^m \right)^{\frac{\eta_x}{\eta_x - 1}} \right\}^{\frac{\eta_x - 1}{\eta_x}} \tag{54}$$

with the following demands for inputs resulting from the cost minimization problem:

$$X_{i,t}^d = (1-\omega_x) \left(\frac{NMC_t^x}{\tau_t^x R_t^x P_t} \right)^{\eta_x} X_{i,t} \tag{55}$$

$$X_{i,t}^{m,x} = (\omega_x) \left(\frac{NMC_t^x}{\tau_t^x R_t^x P_t^{m,x}} \right)^{\eta_x} X_{i,t} \tag{56}$$

where τ_t^x behaves again like a markup shock that does not appear in the production function; ω_x is the share of imported goods used in the production of exports $(X_{i,t})$; R_t^x represents the gross nominal interest rate paid by exporting firms given the presence of a working capital channel. The expression for R_t^x is given by:

$$R_t^x = \nu^x R_t + 1 - \nu^x \tag{57}$$

where R_t is the domestic nominal interest rate and ν^x is the proportion of inputs that is financed in advance by loans taken in domestic currency.

NMC_t^x is the nominal marginal cost in the cost minimization problem, with the real marginal cost being defined as $mc_t^x = \frac{NMC_t^x}{S_t P_t^x}$ and having the following representation:

$$mc_t^x = \frac{\tau_t^x R_t^x}{S_t P_t^x} \left\{ (1-\omega_x) P_t^{1-\eta_x} + (\omega_x) \left(P_t^{m,x} \right)^{1-\eta_x} \right\}^{\frac{1}{1-\eta_x}} \tag{58}$$

Integrating (55) and (56) over the (0,1) continuum of specialized exporters results in the aggregate demand of the exporting sector for domestic intermediate and imports used in the production of exports goods.

Each exporter exercise monopolistic power over its product, given the demand coming from the aggregating firm. Again, (local currency) price setting at firm level is modeled in a time dependent fashion *à la* Calvo, with ξ_x representing the probability that firms cannot reoptimize their prices. In this latter case, they index their last period price $(P_{i,t-1}^x)$ by a weighted average of last period inflation (π_{t-1}^x) and steady state inflation of exports (π^x, assumed equal with the steady state value of foreign inflation, given that prices are set in foreign currency) given by:

$$P_{i,t}^x \equiv \left(\pi_{t-1}^x \right)^{\kappa_x} \left(\pi^x \right)^{1-\kappa_x} P_{i,t-1}^x \tag{59}$$

With probability $1-\xi_x$ exporters reoptimize their prices and choose the new price to maximize the present discounted value of profits, that is:

$$E_t \sum_{j=0}^{\infty} \beta^j \upsilon_{t+j} [P^x_{i,t+j} X_{i,t+j} - mc^x_{t+j} P^x_{t+j} X_{i,t+j}] \quad (60)$$

subject to the demand given by (52).

2.3 Banks

Banks are important in the model, as they represent the intermediary through which financial transactions between agents take place. In modeling the financial sector we depart from Christiano et al. (2011) in the following two dimensions:

- first, we assume there are two types of entrepreneurs according to the currency denomination of the loan they take from the banks: those that borrow in domestic currency (DC) representing a fraction ω_k of the total population of entrepreneurs and those borrowing in foreign currency (FC) representing the remaining fraction, $1 - \omega_k$. All the foreign currency transactions that go through the financial sector are assumed to be in euros. It is also assumed that each type of entrepreneurs deals with a specific bank an there is no transition from one type to the other for both entrepreneurs and banks.

- second, there are two types of (consolidated) banks: one type operates entirely using domestic currency, while the other one uses only foreign currency products. The latter $(1 - \omega_k)$ units make risky loans to entrepreneurs borrowing in foreign currency, while the remaining ω_k deal with entrepreneurs borrowing in domestic currency, each type using a financial contract as described in section 2.4. Banks operating with domestic currency raise deposits from domestic households and channel the funds towards the corresponding entrepreneurs. On the other hand, banks dealing with foreign currency funds raise deposits in foreign currency from domestic households and from abroad[9] and channel them towards the entrepreneurs borrowing in foreign currency. Households' savings in domestic currency are remunerated at the deposit rate (assumed here, given the absence of other frictions, equal with interbank interest rate[10]. As for foreign currency funds, they are remunerated with a foreign interest rate, indexed with a risk premium.

A perfectly competitive environment is assumed for banks. At time t, bank i operating with domestic currency funds collects deposits, $D^{DC}_{t+1}(i)$, from domestic households at cost R_t and channels them towards the corresponding entrepreneurs in form of a loan $\left(L^{DC}_{t+1}(i)\right)$. As for each bank i operating with foreign currency denominated funds, it collects deposits $\left(D^{FC}_{t+1}(i)\right)$ from abroad and domestic households, at cost $R^{EUR}_t \Phi_t$, lending the funds $\left(L^{FC}_{t+1}(i)\right)$ towards the corresponding entrepreneurs. Both when attracting and lending foreign currency denominated funds, banks pay/receive an interest rate that is adjusted with a risk premium. In this simple setup financing in foreign currency from abroad or from domestic households

[9]Foreign borrowing can be thought here in terms of net foreign liabilities.

[10]In the absence of other frictions, it is assumed here that the monetary authority manages the liquidity on the interbank market such that the interbank interest rate is equal with the monetary policy interest rate.

are assumed to be perfect substitutes $\left(D^{FC,hh}_{t+1}(i) + FB_{t+1}(i)\right)$. However, this does not necessarily mean that the two components are not identifiable. Total deposits in foreign currency result from the corresponding entrepreneurs' problem, while external financing (FB_{t+1}) represents the external liabilities of the domestic economy, having a law of motion derived from the balance of payments identity. The foreign currency deposits of the households are retrieved as residual.

The Bernanke et al. (1999) type of financial contracts between banks and entrepreneurs for both domestic and foreign currency denominated loans are described in detail in section 2.4.

2.3.1 Equilibrium in the financial sector

Market clearing conditions for deposits:

$$\int_0^1 D^{DC}_{t+1}(j)dj = \text{Deposit supply in DC} \tag{61}$$

$$= \text{Deposit demand in DC} = \int_0^{\omega_k} D^{DC}_{t+1}(i)di = \omega_k D^{DC}_{t+1} \tag{62}$$

$$\int_0^1 D^{FC,hh}_{t+1}(j)dj + \int_0^1 FB_{t+1}(j)dj = \text{Deposit supply in FC} \tag{63}$$

$$= \text{Deposit demand in FC} = \int_{\omega_k}^1 D^{FC}_{t+1}(i)di = (1-\omega_k) D^{FC}_{t+1} \tag{64}$$

Market clearing conditions for loans between banks and entrepreneurs:

$$\omega_k D^{DC}_{t+1} = \text{Supply of DC loans}$$
$$= \text{Demand of DC loans} = \int_0^{\omega_k} L^{DC}_{t+1}(i)di = \omega_k L^{DC}_{t+1}$$

$$(1-\omega_k) D^{FC}_{t+1} = \text{Supply of FC loans}$$
$$= \text{Demand of FC loans} = \int_{\omega_k}^1 L^{FC}_{t+1}(i)di = (1-\omega_k) L^{FC}_{t+1}$$

2.3.2 Further developments in modeling the banking sector

There are a number of simplifying assumptions made that can be relaxed/modified in order to further develop the banking side of the model. For example, perfect competition was assumed for banks. One can instead proceed along the ways presented in Gerali et al. (2010), separate each (consolidated) bank in deposit and lending units and assume that deposit units operate, when dealing with retail clients, in a monopolistic competition environment. In this way, one can study how the interest rate pass-through affects the transmission of monetary policy shocks in the economy.

Another assumption regards the lack of an explicit role for bank capital in the model[11]. Again, the model can be adapted along the lines of Gerali et al. (2010) in order to have a role for bank equity in affecting loan supply conditions. Furthermore, the interaction of banks in the interbank markets can be extended to allow, for example, for departures of the interbank interest rates from the policy rate given the liquidity management policy of the central bank.

Last but not least, minimum reserve requirements, both for domestic and foreign currency deposits, can be introduced in the model, as additional policy tools. One can proceed in a simple way and assume that reserves kept at the central bank are remunerated with a zero interest rate and that commercial banks keep no excess reserves with the monetary authority. Both these assumptions, with the first one being, at least for emerging economies, stronger than the second one, can be relaxed, for example, along the lines presented by Glocker and Towbin (2012).

2.4 Entrepreneurs

Christiano et al. (2011) introduce financial frictions in the model using the purely asymmetric information and costly state verification model of Bernanke et al. (1999), as implemented by Christiano et al. (2003). Considering the existence of asymmetric information (i.e. the individual entrepreneur observes the individual project return after operating the project, while the bank does not observe it), a classic equilibrium concept cannot be used given that the demand for loans would be infinite for any interest rate. Therefore, one needs to rely on an equilibrium concept based on a standard nominal debt contract between banks and entrepreneurs that specifies both an interest rate and a loan amount.

The main difference compared with the approach presented by Christiano et al. (2011) is that we assume there are two types of entrepreneurs according to the currency denomination of the loan they take from banks: those that borrow in domestic currency (DC) representing a fraction ω_k of the total population of entrepreneurs and those borrowing in foreign currency (FC, euros in our case) representing the remaining fraction, $1 - \omega_k$. Unsal (2013) evaluates the impact of macroprudential policies[12] in a calibrated two country model in which entrepreneurs from the smaller economy borrow in domestic or foreign currency. However, relative to our approach, the ratio of entrepreneurs borrowing in domestic relative to those borrowing in foreign currency is undetermined in his model, while in our model is calibrated to match the empirical observed domestic to foreign currency ratio of new loans to non-financial institutions. Moreover, he does not take into account the imperfect substitution between capital (services) provided by entrepreneurs to the intermediate domestic goods

[11] However, in a Bernanke et al. (1999) context, as the one presented here, some of the entrepreneurs can be viewed as financial firms. Dib (2010a) and Dib (2010b) allow for an explicit role for (costly to raise) bank capital that is subject to regulatory requirements.

[12] They introduce in the spreads the entrepreneurs face a component reflecting the impact of (macroprudential) regulation. Furthermore, the model is evaluated with different Taylor rules, some of them incorporating financial variables (e.g. the deviation of credit from its steady state value).

producers. Regarding the latter aspect, our approach is similar with that of Verona et al. (2011), which extends the model of Christiano et al. (2010) with a shadow banking system.

As mentioned before, it is also assumed that each type of entrepreneurs deals with specific banks an there is no transition from one type to the other for both entrepreneurs and banks. Inside each type (DC or FC), at any point in time, there are entrepreneurs with all different levels of net worth and for every level of net worth there is a sufficiently large mass of entrepreneurs that experience a certain productivity shock and deal with a specific bank. As mentioned before, banks are perfectly competitive and borrow the funds from households (domestic for deposit units dealing with entrepreneurs borrowing in domestic currency and domestic and foreign[13] for those borrowing in foreign currency) at nominally non contingent interest rates. There is free entry and no risk for each type of banks, so there is no problem in being able to pay $R_t/R_t^{EUR}\Phi_t$ back, since it is assumed that banks of each type, although they do not know which entrepreneurs are going to pay back their loans and which not, are dealing with a sufficiently large number of entrepreneurs. Now, although each bank observes the average return across entrepreneurs, in order to observe the individual ex post return it has to pay a monitoring cost that is proportional to the assets the bankrupt entrepreneur has after the idiosyncratic shock was realized[14]. The costly state verification technology also implies that entrepreneurs that cannot pay back their loans truly reveal[15] their state to the banks and turn over all their resources.

2.4.1 The individual entrepreneur

Figure 2, adapted from Christiano et al. (2011), presents the timing of events inside a time period $(t+1)$ for an entrepreneur belonging to a class with a certain level of net worth N belonging to any of the two types assumed, $j \in \{DC, FC\}$.

For each type of entrepreneurs, at the end of period t, the entrepreneurs from a class with a certain level of net worth, that is N^{DC} or N^{FC}, buy new physical installed capital from capital producers in a competitive market at price $P_t P_{k',t}$. Entrepreneurs access loans to cover the part of acquisition cost of capital that remains after self-financing occurs, with the amount of demanded loans being given by:

$$L_{t+1}^{DC,N^{DC}} = P_t P_{k',t} \bar{K}_{t+1}^{DC,N^{DC}} - N_{t+1}^{DC,N^{DC}}$$

$$S_t^{RON/EUR} L_{t+1}^{FC,N^{FC}} = P_t P_{k',t} \bar{K}_{t+1}^{FC,N^{FC}} - N_{t+1}^{FC,N^{FC}} \tag{65}$$

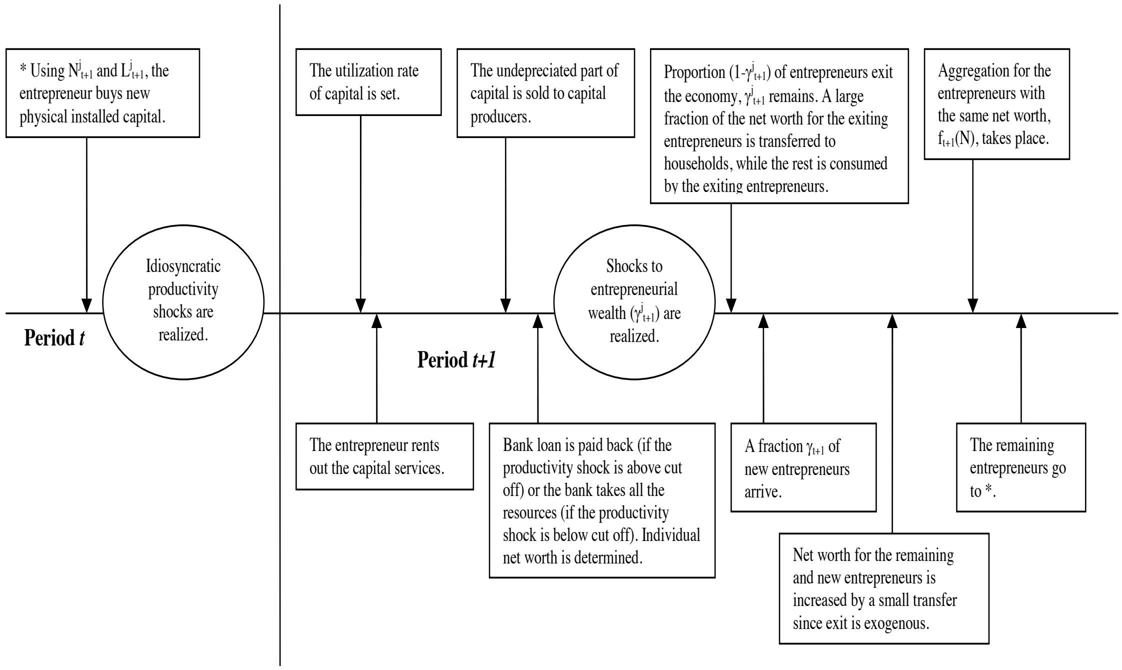
where: $L_{t+1}^{DC,N^{DC}}$ are domestic currency loans; $S_t^{RON/EUR} L_{t+1}^{FC,N^{FC}}$ are foreign currency loans, expressed in domestic currency. As it can be observed from the last equation,

[13] The source of foreign borrowing is not specifically modeled. It is assumed here that the ultimate source of these funds are foreign households. It can as well be foreign banks, mutual funds, etc. without any different impact on the behavior of the model.

[14] Another way to deal with monitoring costs, which in the discussed framework can be thought of reflecting the liquidating costs of the bankrupt entrepreneur, is to assume that they are proportional to the assets of the entrepreneur before the idiosyncratic shock is realized.

[15] There is no incentive for entrepreneurs not to report the true realization of the idiosyncratic productivity shock since the report is irrelevant when the realization is above the cutoff productivity level, while the resources turned when the productivity is below cutoff are lower in value than the interest payments one would make by reporting an above cutoff level of realized individual productivity.

Figure 2: *One period in the life of an entrepreneur with net worth j*



Based on Christiano et al. (2011)

entrepreneurs that borrow in foreign currency are exposed to exchange rate risk, fluctuations in exchange rate inducing balance sheet effects in the model. As in Christiano et al. (2011), it is assumed that entrepreneurs do not borrow the resources from banks that deal with the households they are part of.

Borrowing realized, each entrepreneur is hit by an idiosyncratic productivity shock that transforms physical capital $\bar{K}^{DC,N^{DC}}_{t+1}$ $\left(\bar{K}^{FC,N^{FC}}_{t+1}\right)$ in efficiency units, that is $\omega^{DC}_{t+1}\bar{K}^{DC,N^{DC}}_{t+1}$ $\left(\omega^{FC}_{t+1}\bar{K}^{FC,N^{FC}}_{t+1}\right)$ where: ω^{DC} and ω^{FC} are idiosyncratic productivity shocks with unit mean, log-normally distributed with $var(\log(\omega^j)) = \left(\sigma^j_t\right)^2$, with $j \in \{DC, FC\}$. Christiano et al. (2013) call the time-varying cross sectional dispersions of ω^{DC} and ω^{FC}, i.e. σ^{DC}_t and σ^{FC}_t, risk shocks.

The choice of the utilization rate is independent of the net worth the entrepreneurs have[16]. Each entrepreneur from each category sets the utilization rate of capital (u^j_t) after observing the aggregate return rates and prices, taking into account the user cost function, that is $P^i_t a^j(u^j_t)\omega^j$, renting out afterward capital services (i.e. $u^j_{t+1}\omega^j_{t+1}\bar{K}^{j,N^j}_{t+1}$) in a competitive market at a nominal market rental rate $P_{t+1}r^{k,j}_{t+1}$. Operating one unit of physical capital at rate u^j_{t+1} requires the utilization of $a^j(u^j_t)$ units of domestically produced investment goods

[16]Therefore, the superscripts associated with the class the entrepreneurs belong to, i.e. N^{DC} and N^{FC} were deleted.

for maintenance expenditure[17]. The function that describes the cost with the utilization of capital, $a^j(u_t^j)$, is increasing and convex, with the following functional form being adopted:

$$a^j(u^j) = 0.5\sigma_{b,j}\sigma_{a,j}\left(u^j\right)^2 + \sigma_{b,j}(1-\sigma_{a,j})u^j + \sigma_{b,j}((\sigma_{a,j}/2)-1)$$

where $\sigma_{b,j}, \sigma_{a,j}$ are parameters and the function has the following properties: $a^j(1) = 0$; $\left(a^j\right)^{'}(1) = \sigma_{b,j}$, $\left(a^j\right)^{''} = \sigma_{b,j}\sigma_{a,j} > 0$, with $j \in \{DC, FC\}$. The first order condition associated with the utilization of capital is:

$$r_t^{k,j} = \frac{\left(a^j\right)^{'}(u_t^j)P_t^i}{P_t} \tag{66}$$

The undepreciated part of the capital, $(1-\delta_j)P_{t+1}P_{k',t+1}$, is then sold back in competitive markets to capital producers.

Thus, the average (across each type of entrepreneurs) rate of return on period t physical capital is defined as[18]:

$$R_{t+1}^{K,j} = \frac{\left(1-\tau^k\right)\left(P_{t+1}r_{t+1}^{k,j}u_{t+1}^j - a^j(u_{t+1}^j)P_{t+1}^i\right) + (1-\delta_j)P_{t+1}P_{k',t+1} + \tau^k\delta P_t P_{k',t}}{P_t P_{k',t}} \tag{67}$$

with $j \in \{DC, FC\}$. $P_t P_{k',t}$ represents the price of a unit of newly installed physical capital that operates in $t+1$, expressed in domestic currency. Similar with Christiano et al. (2011), the expenditures with operating the capital are deductible from taxes on capital income (τ^k), while physical depreciation is deductible at historical cost.

After selling their undepreciated capital back to the capital producers, entrepreneurs settle their bank loans. The resources available to the entrepreneurs from class N^j that experienced a productivity shock ω^j are $\omega_{t+1}^j R_{t+1}^{k,j} P_t P_{k',t}\bar{K}_{t+1}^{j,N^j}$,with $j \in \{DC, FC\}$. The cutoff values of the idiosyncratic productivity shocks, $\bar{\omega}_{t+1}^{DC}$ and $\bar{\omega}_{t+1}^{FC}$, are defined as the values above which the entrepreneur retains whatever is above the payments made towards the lending units, but below which bankruptcy occurs and the bank takes everything:

$$\bar{\omega}_{t+1}^{DC}R_{t+1}^{k,DC}P_t P_{k',t}\bar{K}_{t+1}^{DC,N^{DC}} = Z_{t+1}^{DC}L_{t+1}^{DC,N^{DC}} \tag{68}$$

$$\bar{\omega}_{t+1}^{FC}R_{t+1}^{k,FC}P_t P_{k',t}\bar{K}_{t+1}^{FC,N^{FC}} = Z_{t+1}^{FC}S_{t+1}^{RON/EUR}L_{t+1}^{FC,N^{FC}} \tag{69}$$

where Z_{t+1}^{DC} and Z_{t+1}^{FC} are the interest rates associated with loans received by the entrepreneurs borrowing in domestic and foreign currency respectively. The state by state zero profit conditions for each type of bank are given by:

$$\left[\Gamma_t\left(\bar{\omega}_{t+1}^{DC};\sigma_t^{DC}\right) - \mu_{DC}G_t(\bar{\omega}_{t+1}^{DC};\sigma_t^{DC})\right]R_{t+1}^{k,DC}P_t P_{k',t}\bar{K}_{t+1}^{DC,N^{DC}} = R_t L_{t+1}^{DC,N^{DC}} \tag{70}$$

[17]The choice of the utilization rate is independent of the net worth the entrepreneurs have. Therefore, the superscripts associated with the class the entrepreneurs belong to, i.e. N^{DC} and N^{FC} were deleted.

[18]The individual, after taxes, return earned by an entrepreneur that experiences an idiosyncratic productivity shock is $\omega^j R_{t+1}^{K,j}$, with $j \in \{DC, FC\}$.

$$\left[\Gamma_t\left(\bar{\omega}_{t+1}^{FC};\sigma_t^{FC}\right)-\mu_{FC}G_t(\bar{\omega}_{t+1}^{FC};\sigma_t^{FC})\right]R_{t+1}^{k,FC}P_tP_{k',t}\bar{K}_{t+1}^{FC,N^{FC}}=R_t^{EUR}\Phi_tS_{t+1}^{RON/EUR}L_{t+1}^{FC,N^{FC}} \tag{71}$$

With $\varrho_t^{DC}=\frac{P_tP_{k',t}\bar{K}_{t+1}^{DC,N^{DC}}}{N_{t+1}^{DC,N^{DC}}}$ and $\varrho_t^{FC}=\frac{P_tP_{k',t}\bar{K}_{t+1}^{FC,N^{FC}}}{S_t^{RON/EUR}N_{t+1}^{FC,N^{FC}}}$ representing the sectorial leverage ratios, independent of net worth levels, the above expressions can be rewritten as:

$$\left[\Gamma_t\left(\bar{\omega}_{t+1}^{DC};\sigma_t^{DC}\right)-\mu_{DC}G_t\left(\bar{\omega}_{t+1}^{DC};\sigma_t^{DC}\right)\right]\frac{R_{t+1}^{k,DC}}{R_t}=\frac{\varrho_t^{DC}-1}{\varrho_t^{DC}} \tag{72}$$

$$\left[\Gamma_t\left(\bar{\omega}_{t+1}^{FC};\sigma_t^{FC}\right)-\mu_{FC}G_t\left(\bar{\omega}_{t+1}^{FC};\sigma_t^{FC}\right)\right]\frac{R_{t+1}^{k,DC}}{R_t^{EUR}\Phi_t\frac{S_{t+1}^{RON/EUR}}{S_t^{RON/EUR}}}=\frac{\varrho_t^{FC}-1}{\varrho_t^{FC}} \tag{73}$$

where: μ_{DC} and μ_{FC} - parameters governing the monitoring costs; Φ_t is the external (sovereign, country specific) risk premium; $G_t(\bar{\omega}_{t+1}^j;\sigma_t^j)=\int_0^{\bar{\omega}_{t+1}^j}\omega^j dF_t(\omega^j;\sigma_t^j)$ represents the average ω^j value across bankrupt entrepreneurs, with $F_t(\omega^j;\sigma_t^j)$ being the cdf of ω; $\Gamma_t\left(\bar{\omega}_{t+1}^j;\sigma_t^j\right)=\bar{\omega}_{t+1}^j\left[1-F_t(\bar{\omega}_{t+1}^j;\sigma_t^j)\right]+G_t(\bar{\omega}_{t+1}^j;\sigma_t^j)$, is the share of gross return given to the bank with $j\in\{DC,FC\}$.

A note should be made regarding the cost of foreign currency funds. Namely, it is assumed, that banks (both lending units on funds deposited by deposit units, as well as the deposit units on foreign currency deposits made by households) pay an interest rate that is adjusted with the value of the risk premium. Here we implicitly assume that the costs associated with changes in the risk premium are fully transferred by banks[19] towards the entrepreneurs borrowing in foreign currency. The definition of the risk premium is presented in section 2.10.1.

The expected entrepreneurial utilities, normalized by the proceedings that would have been obtained if net worth had been deposited at the bank, are given by:

$$E_t\left\{\frac{\int_{\bar{\omega}_{t+1}^{DC}}^{\infty}\left[R_{t+1}^{k,DC}\omega^{DC}P_tP_{k',t}\bar{K}_{t+1}^{DC,N^{DC}}-Z_{t+1}^{DC}L_{t+1}^{DC,N^{DC}}\right]dF(\omega^{DC};\sigma_t^{DC})}{N_{t+1}^{DC,N^{DC}}R_t}\right\} \tag{74}$$

$$E_t\left\{\frac{\int_{\bar{\omega}_{t+1}^{FC}}^{\infty}\left[R_{t+1}^{k,FC}\omega^{FC}P_tP_{k',t}\bar{K}_{t+1}^{FC,N^{FC}}-Z_{t+1}^{FC}S_{t+1}^{RON/EUR}L_{t+1}^{FC,N^{FC}}\right]dF(\omega^{FC};\sigma_t^{FC})}{N_{t+1}^{FC,N^{FC}}R_t^{EUR}\Phi_t\frac{S_{t+1}^{RON/EUR}}{S_t^{RON/EUR}}}\right\} \tag{75}$$

Using the above relations to eliminate the leverage, the following expressions result:

$$E_t\left\{\left(1-\Gamma_t\left(\bar{\omega}_{t+1}^{DC};\sigma_t^{DC}\right)\right)\frac{R_{t+1}^{k,DC}}{R_t}\frac{1}{1-\frac{\left[\Gamma_t\left(\bar{\omega}_{t+1}^{DC};\sigma_t^{DC}\right)-\mu_{DC}G_t(\bar{\omega}_{t+1}^{DC};\sigma_t^{DC})\right]R_{t+1}^{k,DC}}{R_t}}\right\} \tag{76}$$

[19]Given the way banks are represented in this model, there is no currency mismatch in their balance sheets.

$$E_t\left\{\left(1-\Gamma_t\left(\bar{\omega}^{FC}_{t+1};\sigma^{FC}_t\right)\right)\frac{R^{k,FC}_{t+1}}{\frac{S^{RON/EUR}_{t+1}}{S^{RON/EUR}_t}R^{EUR}_t\Phi_t}\frac{1}{1-\frac{\left[\Gamma_t\left(\bar{\omega}^{FC}_{t+1};\sigma^{FC}_t\right)-\mu_{FC}G_t(\bar{\omega}^{FC}_{t+1};\sigma^{FC}_t)\right]R^{k,FC}_{t+1}}{\frac{S^{RON/EUR}_{t+1}}{S^{RON/EUR}_t}R^{EUR}_t\Phi_t}}\right\} \tag{77}$$

The FOCs resulting from the maximization of the above expected utility function (log of) are given by:

$$E_t\left\{\frac{1-F_t(\bar{\omega}^{DC}_{t+1})}{1-\Gamma_t\left(\bar{\omega}^{DC}_{t+1}\right)}-\frac{\frac{R^{k,DC}_{t+1}}{R_t}\left[1-F_t(\bar{\omega}^{DC}_{t+1})-\mu_{DC}\bar{\omega}^{DC}_{t+1}F'(\bar{\omega}^{DC}_{t+1})\right]}{1-\frac{R^{k,DC}_{t+1}}{R_t}\left[\Gamma_t(\bar{\omega}^{DC}_{t+1})-\mu_{DC}G_t(\bar{\omega}^{DC}_{t+1})\right]}\right\}=0 \tag{78}$$

$$E_t\left\{\frac{1-F_t(\bar{\omega}^{FC}_{t+1})}{1-\Gamma_t\left(\bar{\omega}^{FC}_{t+1}\right)}-\frac{\frac{R^{k,FC}_{t+1}}{\frac{S^{RON/EUR}_{t+1}}{S^{RON/EUR}_t}R^{EUR}_t\Phi_t}\left[1-F_t(\bar{\omega}^{FC}_{t+1})-\mu_{FC}\bar{\omega}^{FC}_{t+1}F'(\bar{\omega}^{FC}_{t+1})\right]}{1-\frac{R^{k,FC}_{t+1}}{\frac{S^{RON/EUR}_{t+1}}{S^{RON/EUR}_t}R^{EUR}_t\Phi_t}\left[\Gamma_t(\bar{\omega}^{FC}_{t+1})-\mu_{FC}G_t(\bar{\omega}^{FC}_{t+1})\right]}\right\}=0 \tag{79}$$

The first term in the above first order conditions for the entrepreneurial utility represents the expected return elasticity with respect to $\bar{\omega}^j_{t+1}$, while the second is the elasticity of the leverage ratio with respect to $\bar{\omega}^j_{t+1}$, $j\in\{DC,FC\}$. Once the value of $\bar{\omega}^j_{t+1}$ is obtained, one could recover the leverage value using banks' zero profit condition. Using the cutoff value definitions, the interest rates associated with loans received by entrepreneurs can be recovered as:

$$Z^{DC}_{t+1}=R^{k,DC}_{t+1}\bar{\omega}^{DC}_{t+1}\frac{\varrho^{DC}_t}{\varrho^{DC}_t-1} \tag{80}$$

for domestic currency loans and

$$Z^{FC}_{t+1}=\frac{R^{k,FC}_{t+1}}{\frac{S^{RON/EUR}_{t+1}}{S^{RON/EUR}_t}}\bar{\omega}^{FC}_{t+1}\frac{\varrho^{FC}_t}{\varrho^{FC}_t-1} \tag{81}$$

for foreign currency loans. Similar to Christiano et al. (2011), for entrepreneurs that borrow in domestic currency the interest rate spread is defined as:

$$spread^{DC}_t=Z^{DC}_{t+1}-R_t \tag{82}$$

while for those borrowing in foreign currency it is

$$spread^{FC}_t=Z^{FC}_{t+1}-R^{EUR}_t\Phi_t. \tag{83}$$

2.4.2 Net worth aggregates

The net worth of an entrepreneur who in period $t-1$ had net worth N^{DC} after settling their loans with lending banks in period t is given by:

$$V_t^{DC,N^{DC}} = \left[1 - \Gamma_t\left(\bar{\omega}_t^{DC};\sigma_{t-1}^{DC}\right)\right] R_{t+1}^{k,DC} P_t P_{k',t} \bar{K}_{t+1}^{DC,N^{DC}} \tag{84}$$

with law of motion of average net worth across all entrepreneurs that borrow in domestic currency being:

$$\bar{N}_{t+1}^{DC} = \gamma_t^{DC} \left\{ \begin{array}{c} R_t^{k,DC} P_{t-1} P_{k',t-1} \bar{K}_t^{DC} - R_{t-1}\left(P_{t-1}P_{k',t-1}\bar{K}_t^{DC} - \bar{N}_t^{DC}\right) \\ -\mu_{DC} \int_0^{\bar{w}_t^{DC}} \omega^{DC} dF(\omega_t^{DC};\sigma_{t-1}^{DC}) R_t^{k,DC} P_{t-1} P_{k',t-1} \bar{K}_t^{DC} \end{array} \right\} + W_t^{e,DC} \tag{85}$$

For those entrepreneurs that borrow in foreign currency, the similar variables are defined as:

$$V_t^{FC,N^{FC}} = \left[1 - \Gamma_t\left(\bar{\omega}_t^{FC};\sigma_{t-1}^{FC}\right)\right] R_{t+1}^{k,FC} P_t P_{k',FC,t} \bar{K}_{t+1}^{FC,N^{FC}} \tag{86}$$

$$\bar{N}_{t+1}^{FC} = \gamma_t^{FC} \left\{ \begin{array}{c} R_t^{k,FC} P_{t-1} P_{k',t-1} \bar{K}_t^{FC} - \frac{S_t^{RON/EUR}}{S_{t-1}^{RON/EUR}} R_{t-1}^{EUR} \Phi_{t-1}\left(P_{t-1}P_{k',t-1}\bar{K}_t^{FC} - \bar{N}_t^{FC}\right) \\ -\mu_{FC} \int_0^{\bar{w}_t^{FC}} \omega^{FC} dF(\omega_t^{FC};\sigma_{t-1}^{FC}) R_t^{k,FC} P_{t-1} P_{k',t-1} \bar{K}_t^{FC} \end{array} \right\} + W_t^{e,FC} \tag{87}$$

The average net worth for each type of entrepreneurs is the sum of entrepreneurs' earnings net of interest rate payments on previous period bank loans and monitoring costs, weighted by the probability of remaining in the economy, γ_t^j, the latter interpreted here as a shock to net worth, plus the transfers received from households, $W_t^{e,j}$. The transfers are received by both remaining entrepreneurs and new entrants, given that the latter category and the remaining bankrupt entrepreneurs, since exit is exogenous, have zero net worth.

A note should be made regarding the aggregation across entrepreneurs. As Christiano et al. (2011) point out, this is potentially complicated due to the different histories the entrepreneurs experienced. Accordingly, one would expect that the density of entrepreneurs with a certain level of net worth $f_{t+1}(N)$ to matter for aggregation. However, this is not the case given that, as mentioned above, the leverage and the interest rate are independent of a certain level of net worth, with the latter aspect resulting from the functional form assumed in the model, namely that the entrepreneurs operate with a (locally) constant returns to scale technology and have a constant returns utility function.

Furthermore, as mentioned before, entrepreneurs that borrow in domestic currency (DC type entrepreneurs) represent a fraction ω_k of the total population, while the remaining $1-\omega_k$ fraction is represented by entrepreneurs borrowing in foreign currency (the FC type entrepreneurs).

2.5 Households

In the baseline new Keynesian model with sticky wages, wage setting is usually introduced following the approach of Erceg et al. (2000) (i.e. households set their wage as they monopolistically supply labor services towards an agent that aggregates them and meets the demand of labor from the domestic intermediate producers). The introduction of employment frictions implies that the supply of labor towards the intermediate goods producers is done by employment agencies that negotiate with each worker the corresponding wage. The utility of the household is given now by:

$$E_t \sum_{l=0}^{\infty} \beta^l \left\{ \zeta^c_{t+l} \log(C_{t+l} - b\bar{C}_{t+l-1}) - \zeta^h_{t+l} A_L \left[\sum_{j=0}^{N-1} \frac{(\varsigma_{j,t+l})^{1+\sigma_L}}{1+\sigma_L} \left[1 - \int_0^{\bar{a}^j_{t+l}} dF(a, \sigma_{a,t+l}) \right] l^j_{t+l} \right] \right\} \tag{88}$$

where: $j \in \{0, ...N-1\}$ is the index of the cohort to which the employment agency belongs to, with agencies from cohort 0 renegotiating the wage in the current period, while higher values index past renegotiations rounds; C_{t+l} is consumption level; $\bar{C}_{t+l}$ is the aggregate consumption level; ζ^c_t and ζ^h_t are consumption preferences and labor disutility shocks; b is the degree of (external) habit formation and σ_L is the inverse Frisch elasticity.

The number of workers inside an employment agency at time t that survive the endogenous process is given by:

$$\left[1 - \int_0^{\bar{a}^j_t} dF(a, \sigma_{a,t}) \right] l^j_t \tag{89}$$

where $\int_0^{\bar{a}^j_t} dF(a, \sigma_{a,t})$ measures the number of workers with an employment agency from cohort j that are endogenously separated, as they experience an idiosyncratic productivity shock, a, below a certain threshold drawn ($\bar{a}^j_t$). The shock has unit mean, is log-normally distributed with $var(\log(a)) = \sigma^2_a$ and associated cdf F. The large family assumption guarantees that both the total fraction of workers employed, given by (90), and the allocation across cohorts, as defined in (89), are the same for each household.

$$L_t = \sum_{j=0}^{N-1} \left[1 - \int_0^{\bar{a}^j_t} dF(a, \sigma_{a,t}) \right] l^j_t \tag{90}$$

The income received by a certain household from participating on the labor market is given by:

$$(1-\tau^y)(1-L_t)P_t b^u z^+_t + \sum_{j=0}^{N-1} W^j_t \left[1 - \int_0^{\bar{a}^j_t} dF(a, \sigma_{a,t}) \right] l^j_t \varsigma_{j,t} \frac{1-\tau^y}{1+\tau^w} \tag{91}$$

In any period t, the budget constraint of the household in nominal terms, expressed in domestic currency, is given by:

$$P_t^c(1+\tau^c)C_t + D_{t+1}^{DC} + S_t^{RON/EUR}D_{t+1}^{FC,hh} = TR_t + FTR_t + profits_t + \left[R_{t-1}^{d,DC} - \tau^{d,DC}(R_{t-1}^{d,DC}-1)\right]D_t^{DC} +$$
$$\left[S_t^{RON/EUR}R_{t-1}^{d,FC}\Phi_{t-1} - \tau^{d,FC}(S_t^{RON/EUR}R_{t-1}^{d,FC}\Phi_{t-1} - S_{t-1}^{RON/EUR})\right]D_t^{FC,hh} +$$
$$(1-\tau^y)(1-L_t)P_t b^u z_t^+ + \sum_{j=0}^{N-1} W_t^j \left[1 - \int_0^{\bar{a}^j} dF(a,\sigma_{a,t})\right] l_t^j \varsigma_{j,t} \frac{1-\tau^y}{1+\tau^w} \tag{92}$$

where:

- expenditures are given by:
  - $P_t^c(1+\tau^c)C_t$ are resources spent on consumption goods, with τ^c being a consumption tax;
  - D_{t+1}^{DC} are period t domestic currency deposits in the corresponding banks for which a non-contingent interest rate $R_t^{d,DC}$ will be received at time $t+1$;
  - $S_t^{RON/EUR}D_{t+1}^{FC,hh}$ are period t foreign currency (i.e. EUR in our case) deposits converted in domestic currency;
- resources are represented by:
  - labor market income as defined in (91);
  - lump sum transfers received from government (TR_t);
  - foreign transfers received from abroad (FTR_t) , e.g. remittances;
  - profits received from the firms owned by households ($profits_t$);
  - period t earnings on domestic deposits made at $t-1$, net of taxes paid on *nominal* interest rate earnings ($\left[R_{t-1}^{d,DC} - \tau^{d,DC}(R_{t-1}^{d,DC}-1)\right]D_t^{DC}$), with $\tau^{d,DC}$ being the corresponding tax rate;
  - $\left[S_t^{RON/EUR}R_{t-1}^{d,FC}\Phi_{t-1} - \tau^{d,FC}\ (S_t^{RON/EUR}R_{t-1}^{d,FC}\Phi_{t-1} - S_{t-1}^{RON/EUR})\right]D_t^{FC,hh}$ represent period t, domestic currency value, earnings on foreign currency deposits made at $t-1$, net of taxes paid on *nominal* interest rate earnings, where $\tau^{d,FC}$ is the corresponding tax rate and $\Phi_t(nfa_t, \tilde{\phi})$ is the premium on foreign currency deposits.

The following first order conditions with respect to consumption and deposits, both domestic and foreign currency, are derived[20]:

$$C_t : \frac{\zeta_t^c}{C_t - bC_{t-1}} = \upsilon_t P_t^c(1+\tau^c) \tag{93}$$

[20]Here we assume external habit formation in consumption. If internal habit formation would have been used, the first order condition with respect to consumption would have the following form: $\frac{\zeta_t^c}{C_t - bC_{t-1}} - \beta E_t \frac{b\zeta_{t+1}^c}{C_{t+1} - bC_t} = \upsilon_t P_t^c(1+\tau^c)$.

$$D_{t+1}^{DC} : \upsilon_t = \beta E_t \upsilon_{t+1} \left[R_t^{d,DC} - \tau^{d,DC}(R_t^{d,DC} - 1) \right] \tag{94}$$

$$D_{t+1}^{FC,hh} : \upsilon_t S_t^{RON/EUR} = \beta E_t \upsilon_{t+1} \left[S_{t+1}^{RON/EUR} R_t^{d,FC} \Phi_t - \tau^{d,FC}(S_{t+1}^{RON/EUR} R_t^{d,FC} \Phi_t - S_t^{RON/EUR}) \right] \tag{95}$$

2.5.1 The role of labor market frictions

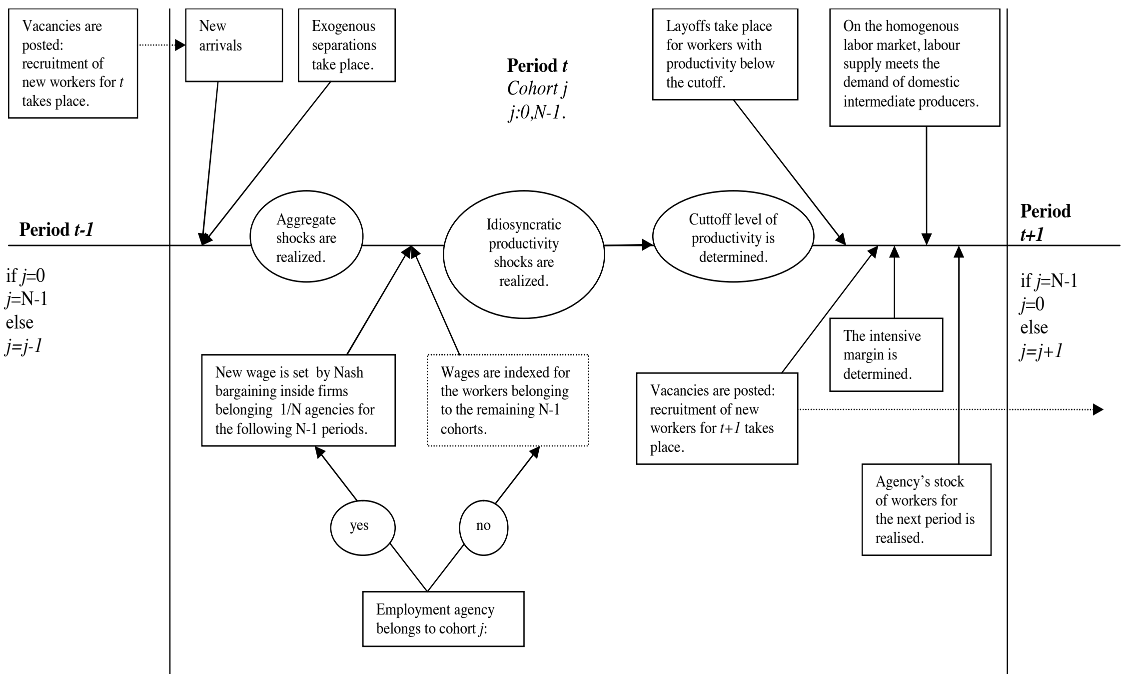
The description of the process of introducing employment frictions follows closely Christiano et al. (2011). Adding employment frictions to the model is done in order to capture both the extensive and the intensive margins of labor supply, as data points towards variation in total hours worked as coming from variations in both margins. Compared with other modeling approaches taken in the literature, such that of Gertler et al. (2008), the novelty introduced by Christiano et al. (2011) resides in the introduction of endogenous separations of workers from their jobs, modeled in a similar fashion with the bankruptcy process at entrepreneur's level.

In this case, labor services are offered to the domestic intermediate producers by employment agencies inside which labor market decisions are taken. Labor force contains workers, with each households having many of them. Each worker enters one period either employed or unemployed with a certain agency, alternating between having one of these states, while remaining part of the same agency. The latter are uniformly and permanently distributed across N cohorts. While unemployed, workers do undirected search, while if employed, workers separate from agencies either exogenously or endogenously (i.e. if their individual productivity is below a certain, endogenously determined, cutoff).

Figure 3 presents the developments taking place in period t, inside an employment agency belonging to cohort j, with $j : 0, N-1$. For ease of exposition, the figure is realized based on the assumption that for employment agencies belonging to cohort j, wage is renegociated in period t. Given the stock of workers from the previous period, new arrivals, determined by recruitment of new workers in the previous period, and exogenous separations take place at the beginning of period t. Afterward, aggregate shocks are realized. As mentioned before, if the employment agency belongs to cohort j a new wage is set by atomistic Nash bargaining inside the $1/N$ proportion of firms for the following $N-1$ periods. Otherwise, each period, wages are indexed for the workers belonging to the remaining $N-1$ cohorts to a combination of previous consumer inflation, current inflation target and (partially to) equilibrium growth of the economy. Wages being set, idiosyncratic productivity shocks are realized. Workers with productivity below the endogenously determined threshold are separated from the agency, while the rest continue their activity. In the next step, employment agencies post vacancies and recruit new workers for period $t+1$. Afterward, the intensive margin of labour supply is chosen and the supply of labor meets the demand of domestic intermediate producers on the homogenous labor market. Similar to Christiano et al. (2011), the developments are presented in a reversed order, as the bargaining problem internalizes the future developments taking place inside the period.

The intensive margin is determined by equating worker's marginal disutility of working in monetary terms (right-hand side of the below equation) with the marginal benefit accruing

Figure 3: *One period for an employment agency*



Based on Christiano et al. (2011)

to the employment agency (left-hand side), when hours worked increase by one unit.

$$W_t \varsigma_t^j = \zeta_t^h A_L \left(\varsigma_{j,t}\right)^{\sigma_L} \frac{1}{\upsilon_t \frac{1-\tau^y}{1+\tau^w}};\ j = 0, ...N-1 \tag{96}$$

where: W_t is the remuneration paid by the domestic intermediate producers to the employment agency for one unit of labor; $\varsigma_{j,t}$ represent the hours worked at time t by a worker from cohort j; $\varsigma_t^j = \frac{\int_{\bar{a}_t^j}^{\infty} a dF(a,\sigma_{a,t})}{1-\int_0^{\bar{a}_t^j} dF(a,\sigma_{a,t})}$ is the expected productivity of a worker conditional that he is not endogenously separated.

In the previous step, for each cohort, j $(0, ..., N-1)$, (monotonic transformations of) *vacancies* are chosen such that the value functions of the employment agencies are maximized. Equation (97) below is the value function for an employment agency from cohort $i = 0$ that renegotiates the wage at time t, with workforce, after exogenous separations and new arrivals, l_t^0, after the wage was set (i.e. $\mathring{\omega}_t$ is an arbitrary value of the wage).

$$F(l_t^0, \mathring{\omega}_t) = \sum_{i=0}^{N-1} \beta^j E_t \frac{\upsilon_{t+i}}{\upsilon_t} \max_{\left(\tilde{\nu}_{t+i}^i, \bar{a}_{t+i}^i\right)} \left[\begin{array}{c} \int_{\bar{a}_{t+i}^i}^{\infty} \left(W_{t+i} a - \Gamma_{t,i} \mathring{\omega}_t\right) \varsigma_{i,t+i} dF(a) \\ -P_{t+i} \frac{\kappa z_{t+i}^+}{\varphi} \left(\tilde{\nu}_{t+i}^i\right)^{\varphi} \left(1 - \int_0^{\bar{a}_{t+i}^i} dF(a, \sigma_{a,t+i})\right) \end{array} \right] l_{t+i}^i \tag{97}$$
$$+ \beta^N E_t \frac{\upsilon_{t+N}}{\upsilon_t} F(l_{t+N}^0, \tilde{W}_{t+N})$$

where: $\Gamma_{t,i}$ is an indexation factor given by equation (98) below; $\tilde{\nu}_{t+i}^i$ is the monotonic transformation of vacancies given by formula (99) below; l_{t+i}^i is the workforce of agency i at time $t+i$ that evolves according to (101); $\frac{\kappa z^{+}_{t+i}}{\varphi}\left(\tilde{\nu}^{i}_{t+i}\right)^{\varphi}$ are the adjustment costs per vacancy; $\tilde{W}_{t+N}$ is the Nash wage corresponding to the next bargaining round taking place at $t+N$, and taken as given at time t.

$$\Gamma_{t,i} \equiv \{ \begin{matrix} \tilde{\pi}_{w,t+i}...\tilde{\pi}_{w,t+1}, & i>0 \\ 1....., & i=0 \end{matrix} \tag{98}$$

$$\tilde{\nu}^{i}_{t+i} \equiv \frac{Q^{\iota}_{t+i}\nu^{i}_{t+i}}{\left(1-\int_0^{\bar{a}^{i}_{t+i}} dF(a,\sigma_{a,t+i})\right) l^{i}_{t+i}} \tag{99}$$

where: Q_{t+i} is the probability of a vacancy being filled; ι is a parameter governing the existence of internal ($\iota = 1$) or search ($\iota = 0$) costs in adjusting the number of workers. The indexation factor is a product of previous indexations to a combination of past consumption inflation, current inflation target and (partially) equilibrium growth of the economy, with:

$$\tilde{\pi}_{w,t+1} \equiv \left(\pi^{c}_{t}\right)^{\kappa_w}\left(\bar{\pi}^{c}_{t+1}\right)^{1-\kappa_w}\left(\mu_{z^+}\right)^{\vartheta_w} \tag{100}$$

Also the labor force for cohort i ($i = 0, ..., N-1$), l^{i+1}_{t+1}, evolves according to:

$$l^{i+1}_{t+1} = \left(\chi^{i}_{t}+\rho\right)\left(1-\int_0^{\bar{a}^{i}_{t}} dF(a,\sigma_{a,t})\right) l^{i}_{t} \tag{101}$$

In equation (101), χ^{i}_{t} is the hiring rate of the employment agency that depends on vacancies according to: $\chi^{i}_{t} = Q^{1-\iota}_{t}\tilde{\nu}^{i}_{t}$ and ρ is the probability that a worker with an agency survives the exogenous separation.

The equation (102) below shows the value function of a worker after he survived the endogenous separation. Hence, at time t, the value of being a worker with an agency from cohort j is equal with the wages received in period t minus the disutility of working (in monetary terms) plus the discounted value of next period's value function. The latter term represents the weighted sum of the value function in case the worker survives both exogenous and endogenous separations in period $t+1$, $\left(\rho(1-\int_0^{\bar{a}^{j+1}_{t+1}} dF(a,\sigma_{a,t+1})V^{j+1}_{t+1}\right)$, and the utility of being unemployed in case the worker does not survive the exogenous *or* the endogenous separation process.

$$V^{j}_{t} = \Gamma_{t-j,j}\tilde{W}_{t-j}\varsigma_{j,t}\frac{1-\tau^{y}}{1+\tau^{w}} - \zeta^{h}_{t}A_{L}\frac{\left(\varsigma_{j,t}\right)^{\sigma_L}}{\left(1+\sigma_L\right)\upsilon_t} + \tag{102}$$
$$\beta E_t\frac{\upsilon_{t+1}}{\upsilon_t}\left[\rho(1-\int_0^{\bar{a}^{j+1}_{t+1}} dF(a,\sigma_{a,t+1})V^{j+1}_{t+1} + \left(1-\rho+\rho\int_0^{\bar{a}^{j+1}_{t+1}} dF(a,\sigma_{a,t+1})\right)U_{t+1}\right]$$

The value function of being unemployed is shown in equation (103). It is the sum of unemployment benefits in monetary terms, adjusted for eventual income taxes, and next period's discounted value function. The latter is also the probability adjusted sum of the utility of being still unemployed in period $t+1$, $(1-f_t)U_{t+1}$, and the value function in case the unemployed person finds a job with an employment agency, $f_t V^{x}_{t+1}$.The latter term, V^{x}_{t+1}, presented in equation (104), is the sum of value functions of workers, $\tilde{V}_{t+1}^{j+1}$ (before being endogenously separated), adjusted with the across cohorts probabilities of being matched with an employment agency.

$$U_t = P_t z_t^+ b^u (1-\tau^y) + \beta E_t \frac{\upsilon_{t+1}}{\upsilon_t} \left[f_t V_{t+1}^x + (1-f_t) U_{t+1} \right] \tag{103}$$

$$V_{t+1}^x = \sum_{j=0}^{N-1} \frac{\chi_t^j \left(1 - \int_0^{\bar{a}_t^j} dF(a,\sigma_{a,t})\right) l_t^j}{m_t} \tilde{V}_{t+1}^{j+1} \tag{104}$$

where total matches m_t is given by $m_t = \sum_{j=0}^{N-1} \chi_t^j \left(1 - \int_0^{\bar{a}_t^j} dF(a,\sigma_{a,t})\right) l_t^j$ and $\tilde{V}_t^j$ evolves according to (105).

$$\tilde{V}_t^j = U_t \int_0^{\bar{a}_t^j} dF(a,\sigma_{a,t}) + (1 - \int_0^{\bar{a}_t^j} dF(a,\sigma_{a,t})) V_t^j \tag{105}$$

The *endogenous separation* process is modeled by Christiano et al. (2011) in a similar way with the approach taken in the case of entrepreneurs when financial frictions are added to the baseline model. As mentioned before, each worker from the labor force within an agency from cohort j (l_t^j) experiences a productivity shock, a, drawn from distribution F. If the shock is below a certain threshold, $\bar{a}_t^j$, the worker separates, while he stays with the agency if the shock is above the threshold.

Christiano et al. (2011) present multiple ways of determining the cutoff inside one agency, based on different weights given to the surplus of the agency and that of the workers inside it. Since we estimated the model with all the weight given to agency's surplus, only the corresponding choice is presented here, while the reader is instructed to consult Christiano et al. (2011) for the detailed discussion.

The agency's surplus, defined in equation (97), is linear in the workforce attached to it, where the agency is assumed again, for simplicity, to belong to cohort 0. $F(l_t^0, \mathring{\omega}_t)$ can be rewritten as $F(l_t^0, \mathring{\omega}_t) = J(\mathring{\omega}_t) l_t^0$, where $J(\mathring{\omega}_t)$ represents the surplus per worker and is given by:

$$J(\mathring{\omega}_t) = \max_{\bar{a}_t^0} \left[1 - \int_0^{\bar{a}_t^0} dF(a,\sigma_{a,t}) \right] \tilde{J}(\mathring{\omega}_t; \bar{a}_t^0) \tag{106}$$

where:

$$\tilde{J}(\mathring{\omega}_t; \bar{a}_t^0) = \max_{\nu_t^0} \left\{ \left(W_t \varsigma_t^0 - \omega_t \right) \varsigma_{0,t} - P_t \frac{\kappa z_t^+}{\varphi} \left(\tilde{\nu}_t^0 \right)^{\varphi} + \beta \frac{\upsilon_{t+1}}{\upsilon_t} (\chi_t^0 + \rho) J_{t+1}^1 (\mathring{\omega}_t) \right\} \tag{107}$$

Therefore, for cohort 0, when only employer's surplus is taken into account, $\bar{a}_t^0$ is chosen to maximize $F(l_t^0, \mathring{\omega}_t)$, which given the above equations can be rewritten as:

$$\max_{\bar{a}_t^0} \left[1 - \int_0^{\bar{a}_t^0} dF(a,\sigma_{a,t}) \right] \tilde{J}(\mathring{\omega}_t; \bar{a}_t^0) l_t^0 \tag{108}$$

with the associated first order condition given by:

$$\tilde{J}_{\bar{a}_t^0}(\mathring{\omega}_t; \bar{a}_t^0) = \tilde{J}(\mathring{\omega}_t; \bar{a}_t^0) \frac{dF(\bar{a}_t^0)}{1 - \int_0^{\bar{a}_t^0} dF(a, \sigma_{a,t})} \tag{109}$$

The *Nash bargaining* problem, the second step in the timeline described in figure (3), after the exogenous separations and new arrivals take place, is solved by maximizing the agency's and worker's surpluses, weighted by their bargaining power, with $\tilde{W}_t$ being the resulting wage.

$$\max_{\mathring{\omega}_t} \left(\tilde{V}_t^0 - U_t\right)^\eta J(\mathring{\omega}_t)^{1-\eta} \tag{110}$$

where η is the bargaining power of the worker and $1 - \eta$ is the bargaining power of the employment agency. Similar problems with the above ones are valid for agencies belonging to cohorts other than 0 and their associated workers.

Relative to the standard small open economy model, the aggregate resource constraint, as presented in section 2.9, is modified to reflect the costs of posting vacancies in terms of domestic intermediate goods.

2.6 Monetary and fiscal authorities

Similar to Christiano et al. (2011), we estimate the model using a version of the Taylor reaction function in which the monetary authority reacts to current inflation deviation of inflation from the target and current deviation of output from its steady-state value, that is:

$$\log\left(\frac{R_t}{R}\right) = \rho_R \log\left(\frac{R_{t-1}}{R}\right) + (1-\rho_R)\left[\log\left(\frac{\bar{\pi}_t^c}{\bar{\pi}^c}\right) + r_\pi \log\left(\frac{\pi_t^c}{\bar{\pi}_t^c}\right) + r_y \log\left(\frac{y_t}{y}\right)\right] + \varepsilon_{R,t} \tag{111}$$

As the inflation target is not constant throughout the estimation period, it is assumed to follow a mean reverting process given by:

$$\log(\bar{\pi}_t^c) = (1 - \rho_{\bar{\pi}^c}) \log(\bar{\pi}^c) + \rho_{\bar{\pi}^c} \log(\bar{\pi}_{t-1}^c) + \varepsilon_{\bar{\pi},t} \tag{112}$$

The model assumes a budget that is always balanced with the help of lump sum transfers. The (stationarized) government expenditures follow an AR(1) process given by:

$$\log(g_t) = (1 - \rho_g)(\eta_{g,real} VA) + \rho_g \log(g_{t-1}) + \varepsilon_{g,t} \tag{113}$$

where $\eta_{g,real}$ measures the steady state real government expenditures to gross value added ratio. Since nominal and real shares of government consumption in GDP are not equal in the data, we depart from Christiano et al. (2011) and assume the price of the government consumption good is different from the price of the final good, the former evolving as:

$$\log(p_t^G) = ar_{1,pg} \log(p_{t-1}^G) + ar_{2,pg} \log\left(\frac{p_{t-1}^G}{p_{t-2}^G}\right) + (1 - ar_{1,pg})\, p^G + \varepsilon_{pg,t} \tag{114}$$

where the steadey state p^G is calibrated such as to match the observed nominal and real shares discrepancy.

As for taxes, there are six of them, assumed constant, present in the model: $\tau^c, \tau^{d,DC}, \tau^{d,FC}, \tau^k, \tau^y, \tau^w$.

2.7 Aggregate variables and (other) market clearing conditions

Aggregate net worth is the defined as:

$$\bar{N}_{t+1}^{total} = \omega_k \bar{N}_{t+1}^{DC} + (1-\omega_k)\bar{N}_{t+1}^{FC} \tag{115}$$

while total loans given to entrepreneurs, expressed in domestic currency are given by:

$$L_{t+1}^{total} = \omega_k L_{t+1}^{DC} + (1-\omega_k) S_t^{RON/EUR} L_{t+1}^{FC} \tag{116}$$

The total stock of physical capital is given by:

$$\bar{K}_{t+1}^{total} = \omega_k \bar{K}_{t+1}^{DC} + (1-\omega_k)\bar{K}_{t+1}^{FC} \tag{117}$$

The aggregate leverage ratio is given by:

$$\varrho_t^{total} = \frac{\text{total assets}}{\text{total net worth}} = \frac{\bar{K}_{t+1}^{total}}{\bar{N}_{t+1}^{total}} = \frac{P_t P_{k',t}\left(\omega_k \bar{K}_{t+1}^{DC} + (1-\omega_k)\bar{K}_{t+1}^{FC}\right)}{\omega_k \bar{N}_{t+1}^{DC} + (1-\omega_k)\bar{N}_{t+1}^{FC}} \tag{118}$$

The capital rental market clearing conditions are given by:

$$\int_0^1 K_{i,t}^{DC,int} di = \int_0^{\omega_k} K_{i,t}^{DC,entrep.} di = \omega_k K_t^{DC} = \omega_k u_t^{DC} \bar{K}_t^{DC} \tag{119}$$

and

$$\int_0^1 K_{i,t}^{FC,int} di = \int_{\omega_k}^1 K_{i,t}^{FC,entrep.} di = (1-\omega_k)\, K_t^{FC} = (1-\omega_k)\, u_t^{FC} \bar{K}_t^{FC} \ . \tag{120}$$

The total transfers from households to both type of entrepreneurs are given by:

$$W_t^{e,HH} = \omega_k W_t^{e,DC} + (1-\omega_k)\, W_t^{e,FC}$$

2.8 Foreign sector

In our model, foreign currency financial transactions take place in EUR, which is consistent with the empirical evidence for Romania. However, when modeling the foreign trade in goods and services, we need to take into account that around one quarter of it is denominated in US dollars. Therefore, we enrich the model by modeling the foreign sector as a two country (Euro area and US) open economies new Keynesian semi-structural model, similar to Pedersen and Ravn (2013). Moreover, the evolution of the price of oil is included, as an exogenous process, as part of the external sector. The modeling of the external sector is close to the one used by Juillard et al. (2008).

2.8.1 The structure of the foreign economies

The simplified structure of the model for foreign sector is shown in figure 4.

For each foreign partner, there is an IS curve, as presented by equations (121) and (122) below, according to which the deviation of domestic output from its steady state value depends positively on expected and previous periods' output gaps, negatively on the expected real interest rate, negatively/positively for Euro area/US on the previous period deviation of the USD/EUR real exchange rate from its equilibrium value[21] and positively on the foreign output gap registered on the previous period, with the latter acting as a proxy for external demand.

$$\begin{aligned} y_t^{EUR,gap} &= is_{eur,bl} y_{t-1}^{EUR,gap} + (1 - is_{eur,bl})\, y_{t+1}^{EUR,gap} \\ &- is_{eur,r} \left[\left(R_t^{EUR} - \pi_{t+1}^{EUR} \right) - \left(R^{EUR} - \pi^{EUR} \right) \right] \\ &- is_{eur,q} \left(q_{t-1}^{USD/EUR} - q^{USD/EUR} \right) + is_{eur,f} y_{t-1}^{USD,gap} + \varepsilon_{y^{EUR},t} \end{aligned} \tag{121}$$

$$\begin{aligned} y_t^{US,gap} &= is_{us,bl} y_{t-1}^{US,gap} + (1 - is_{us,bl})\, y_{t+1}^{US,gap} \\ &- is_{us,r} \left[\left(R_t^{US} - \pi_{t+1}^{US} \right) - \left(R^{US} - \pi^{US} \right) \right] \\ &+ is_{us,q} \left(q_{t-1}^{USD/EUR} - q^{USD/EUR} \right) + is_{us,f} y_{t-1}^{EUR,gap} + \varepsilon_{y^{US},t} \end{aligned} \tag{122}$$

The deviation of the inflation rate from its equilibrium value is approximated for each foreign partner by a Phillips curve equation, having as determinants, as shown in equations (123) and (124) below, past and expected deviations of inflation from the target, current output gap, the current deviation of the change of real exchange rate from its equilibrium value[22] and the current and previous period deviation of the real price of oil, expressed in domestic currency, from its equilibrium value.

$$\begin{aligned} \pi_t^{EUR} - \pi^{EUR} &= pc_{eur,bl} \left(\pi_{t-1}^{EUR} - \pi^{EUR} \right) + (1 - pc_{eur,bl}) \left(\pi_{t+1}^{EUR} - \pi^{EUR} \right) \\ &+ pc_{eur,mc} y_t^{EUR,gap} - pc_{eur,q} \left(\Delta q_t^{USD/EUR} - \Delta q^{USD/EUR} \right) \\ &+ pc_{eur,oil1} \log \left(\frac{poil_t^{USD}}{poil^{USD}} / \frac{q_t^{USD/EUR}}{q^{USD/EUR}} \right) + pc_{eur,oil2} \log \left(\frac{poil_{t-1}^{USD}}{poil^{USD}} / \frac{q_{t-1}^{USD/EUR}}{q^{USD/EUR}} \right) + \varepsilon_{\pi^{EUR},t} \end{aligned} \tag{123}$$

[21] As expressed here, a depreciation of the real exchange rate over its equilibrium value (i.e. a depreciation of USD vis-a-vis EUR in real terms) implies a decrease/increase in the deviation of output from its steady state value for the Euro area/US economy.

[22] As expressed here, a depreciation of the real exchange rate over its equilibrium value implies a decrease/increase in the deviation of the inflation rate from target for the Euro area/US economy.

$$\pi_t^{US} - \pi^{US} = pc_{us,bl}\left(\pi_{t-1}^{US} - \pi^{US}\right) + (1 - pc_{us,bl})\left(\pi_{t+1}^{US} - \pi^{US}\right)$$
$$+ pc_{us,mc} y_t^{US,gap} + pc_{us,q}\left(\Delta q_t^{USD/EUR} - \Delta q^{USD/EUR}\right)$$
$$+ pc_{us,oil1}\log\left(\frac{poil_t^{USD}}{poil^{USD}}\right) + pc_{us,oil2}\log\left(\frac{poil_{t-1}^{USD}}{poil^{USD}}\right) + \varepsilon_{\pi^{US},t} \quad (124)$$

The conduct of monetary policy for each economy is approximated by a Taylor rule with the monetary authority (sluggishly) reacting to current deviation of inflation from the target and current output gap, as shown in equations (125) and (126) :

$$R_t^{EUR} - R^{EUR} = tr_{eur,bl}\left(R_{t-1}^{EUR} - R^{EUR}\right) + (1 - tr_{eur,bl})\left[tr_{eur,y} y_t^{EUR,gap} + tr_{eur,\pi}\left(\pi_t^{EUR} - \pi^{EUR}\right)\right] + \varepsilon_{R^{EUR},t} \quad (125)$$

$$R_t^{US} - R^{US} = tr_{us,bl}\left(R_{t-1}^{US} - R^{US}\right) + (1 - tr_{us,bl})\left[tr_{us,y} y_t^{US,gap} + tr_{us,\pi}\left(\pi_t^{US} - \pi^{US}\right)\right] + \varepsilon_{R^{US},t} \quad (126)$$

The USD/EUR exchange rate is determined according to the following (modified) uncovered interest rate parity condition:

$$(1 - uip^*)\,\Delta S_{t+1}^{USD/EUR} = uip^* \Delta S_t^{USD/EUR} + \left(R_t^{US} - R_t^{EUR}\right) - \varepsilon_{uip^*,t} \quad (127)$$

with $uip^* > 0$. This form of the UIP condition is similar with the one that can be derived in a structural model by assuming a risk premium that depends on the expected change in the exchange rate, as in Adolfson et al. (2007a).

The USD/EUR real exchange rate is defined as:

$$q_t^{USD/EUR} = \frac{S_t^{USD/EUR} P_t^{EUR}}{P_t^{US}} \quad (128)$$

The real price of oil, expressed in US dollars, $poil_t^{USD}$, is modeled as an exogenous process:

$$\log(poil_t^{USD}) = ar_{1,oil}\log(poil_{t-1}^{USD}) + ar_{2,oil}\log\left(\frac{poil_{t-1}^{USD}}{poil_{t-2}^{USD}}\right) + (1 - ar_{1,oil})\,poil^{USD} + \varepsilon_{oilusd,t} \quad (129)$$

where:

$$\log(poil_t^{USD}) = \log\left(\frac{P_t^{oil,USD}}{P_t^{US}}\right) \quad (130)$$

2.8.2 Aggregate external variables and (real effective) exchange rates

Given the modeling of the external sector, the following variables need to be defined, with ω_q being the weight of external trade with goods and services made by domestic agents in EUR and $1 - \omega_q$ in USD:

- aggregate effective foreign output, Y_t^*, a variable that enters the equation reflecting the foreign demand of domestic (Romanian in our case) exports of goods and services, that is (50):

$$\log\left(\frac{Y_t^*}{Y^*}\right) = \omega_q y_t^{EUR,gap} + (1-\omega_q)\, y_t^{US,gap} \tag{131}$$

- aggregate effective foreign inflation rate, defined as:

$$\pi_t^* = \left(\pi_t^{EUR}\right)^{\omega_q} \left(\pi_t^{US}\right)^{1-\omega_q} \tag{132}$$

- aggregate effective foreign interest rate:

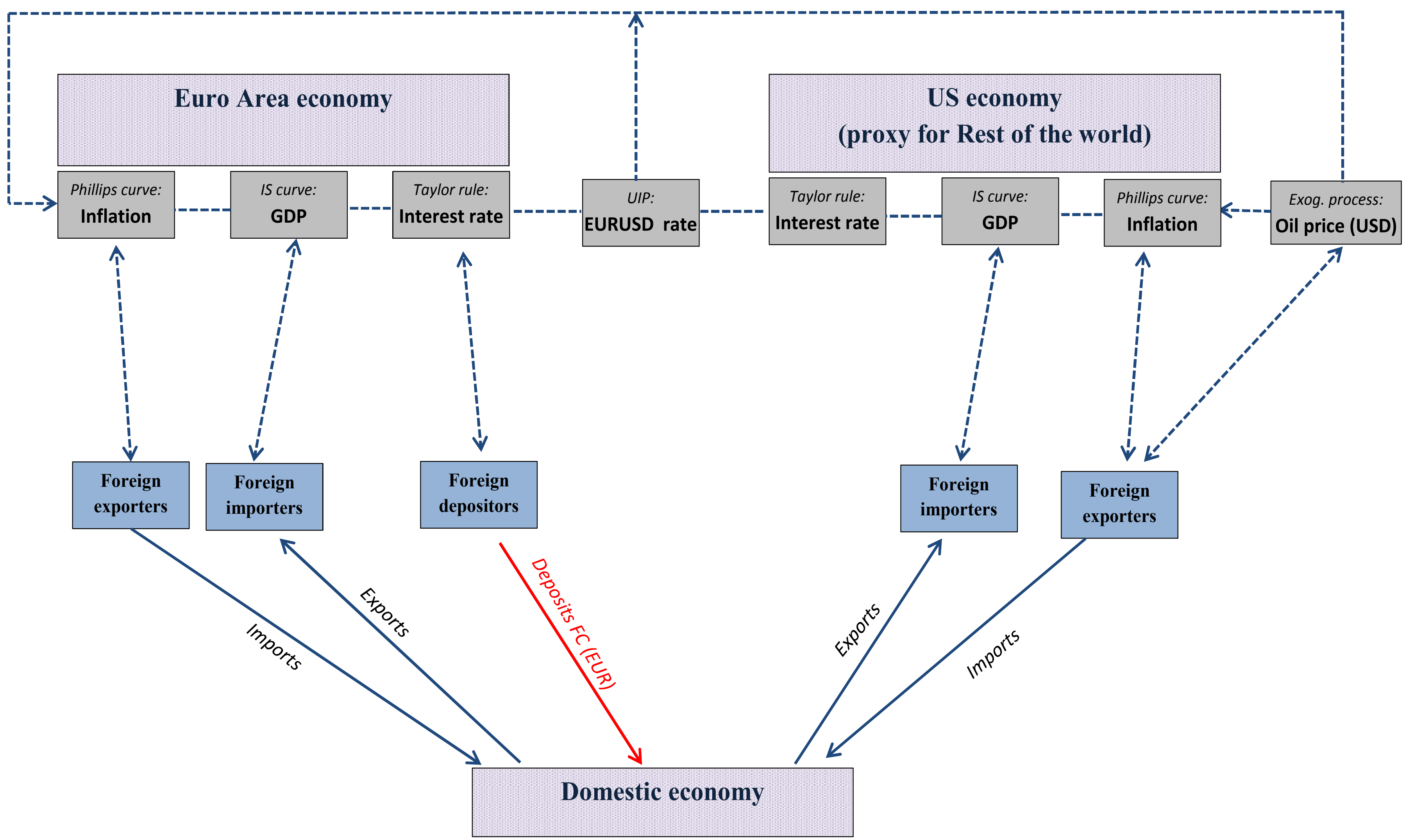
$$R_t^* = \left(R_t^{EUR}\right)^{\omega_q} \left(R_t^{US}\right)^{1-\omega_q} \tag{133}$$

- the effective real exchange rate:

$$\begin{aligned} q_t &= \left(q_t^{RON/EUR}\right)^{\omega_q} \left(q_t^{RON/USD}\right)^{1-\omega_q} \\ &= \left(\frac{S_t^{RON/EUR} P_t^{EUR}}{P_t^c}\right)^{\omega_q} \left(\frac{S_t^{RON/USD} P_t^{US}}{P_t^c}\right)^{1-\omega_q} \\ &= \left[\left(S_t^{RON/EUR}\right)^{\omega_q} \left(S_t^{RON/USD}\right)^{1-\omega_q}\right] \left[\left(\frac{P_t^{EUR}}{P_t^c}\right)^{\omega_q} \left(\frac{P_t^{US}}{P_t^c}\right)^{1-\omega_q}\right] \\ &= \left(\frac{S_t^{ef} P_t^*}{P_t^c}\right) \end{aligned} \tag{134}$$

In our case, trade with financial assets and/or liabilities takes place exclusively in domestic currency and EUR. Implicitly, the uncovered interest rate equation for the domestic economy is in terms of these currencies. The USD/EUR exchange rate is determined outside the domestic economy, as shown above. Implicitly, the domestic currency to USD (real) exchange rate is determined from the cross rates.

Figure 4: *Structure of the external sector of the model*



2.9 Aggregate resource constraint, National Accounts consistent GDP and the GDP deflator

2.9.1 Aggregate resource constraint

Without steady state price dispersion, the following aggregate resource constraint must hold in a symmetric equilibrium:

$$\begin{aligned}
&Y_t - \omega_k \left[\mu_{DC} G_t(\bar{\omega}_t^{DC}; \sigma_{t-1}^{DC}) R_t^{k,DC} P_{t-1} P_{k',t-1} \bar{K}_t^{DC}\right] \\
&- (1-\omega_k) \left[\mu_{FC} G_t(\bar{\omega}_t^{FC}; \sigma_{t-1}^{FC}) R_t^{k,FC} P_{t-1} P_{k',t-1} \bar{K}_t^{FC}\right] \\
&- \sum_{j=0}^{N-1} P_t \frac{\kappa z_t^+}{\varphi} \left(\tilde{\nu}_t^j\right)^{\varphi} (1 - \int_0^{\bar{a}_t^j} dF(a, \sigma_{a,t})) l_t^j \\
&= \frac{P_t^G}{P_t} G_t + \int_0^1 C_{i,t}^d + I_t^d + \int_0^1 X_{i,t}^d
\end{aligned} \tag{135}$$

which using (1), (5), (55), (50), (27) and (31) can be rewritten as[23]:

$$\begin{aligned}
&\left((1-\omega_o)^{\frac{1}{\eta_o}} V A_t^{\frac{\eta_o - 1}{\eta_o}} + \omega_o^{\frac{1}{\eta_o}} \left(Oil_t^m\right)^{\frac{\eta_o-1}{\eta_o}}\right)^{\frac{\eta_o}{\eta_o-1}} - z_t^+ \phi \\
&- \omega_k \left[\mu_{DC} G_t(\bar{\omega}_t^{DC}; \sigma_{t-1}^{DC}) R_t^{k,DC} P_{t-1} P_{k',t-1} \bar{K}_t^{DC}\right] \\
&- (1-\omega_k) \left[\mu_{FC} G_t(\bar{\omega}_t^{FC}; \sigma_{t-1}^{FC}) R_t^{k,FC} P_{t-1} P_{k',t-1} \bar{K}_t^{FC}\right] \\
&- \sum_{j=0}^{N-1} P_t \frac{\kappa z_t^+}{\varphi} \left(\tilde{\nu}_t^j\right)^{\varphi} (1 - \int_0^{\bar{a}_t^j} dF(a, \sigma_{a,t})) l_t^j \\
&= \frac{P_t^G}{P_t} G_t + I_t^d + (1-\omega_c) \left\{(1-\omega_c) + (\omega_c) \left(\frac{P_t^{m,c}}{P_t}\right)^{1-\eta_c}\right\}^{\frac{\eta_c}{1-\eta_c}} C_t \\
&+ (1-\omega_x) \left\{(1-\omega_x) + (\omega_x) \left(\frac{P_t^{m,x}}{P_t}\right)^{1-\eta_x}\right\}^{\frac{\eta_x}{1-\eta_x}} \left(\frac{P_t^x}{P_t^*}\right)^{-\eta_f} Y_t^*
\end{aligned} \tag{136}$$

In a model without imported oil in the domestic intermediate production function, Christiano et al. (2011) subtract the monitoring, hiring and capital utilization costs from Y_t, when matching GDP to the data. The corresponding measure of their domestic output is, in our model, VA_t. If one considers this measure, adjusted with the above mentioned costs, to be the correspondent of GDP as measured in the data, using P_t as the model corresponding measure of the GDP deflator as measured in the data would be incorrect, given the presence of

[23]Although only intermediate domestic goods are used in the production of G_t, the presence of P_t^G/P_t^y ratio is justified in order to match the data discrepancy between nominal and real government consumption shares in GDP.

imported goods (i.e. oil in our case) in it. A more appropriate measure would be represented by P_t^{VA}, that is the part of the marginal cost of intermediate good producers that does not reflect the influence of imported oil. However, using in practice this measure to proxy for data related GDP deflator is inconvenient given at least the following reasons: while P_t is sticky, P_t^{VA} is not sticky[24]; certain empirical regularities regarding the behavior of the GDP deflator are not matched when looking at the impulse response functions that show the change in P_t^{VA} as a result of applying different shocks present in the model (the effect of the shock is short lived, signs are inconsistent); given at least the latter two facts, using P_t^{VA} as GDP deflator would also result in monitoring, hiring and capital utilization costs being deflated by it, with relatively important changes in the behavior of data consistent real GDP.

One alternative measure used in the literature (e.g. Adjemian and Darracq Paries (2008)) to attenuate part of the above mentioned drawbacks is given by the following definition of the GDP deflator:

$$P_t^{GDP} = \frac{P_t Y_t - P_t^{oil} Oil_t}{VA_t} \tag{137}$$

The above P_t^{GDP} measure has the advantage that it inherits the stickiness of P_t (and P_t^{oil}), while still excluding the effect of oil imported goods. However, in our paper we use an alternative, national accounts consistent measure of nominal GDP and an alternative definition of the GDP deflator. The following two subsections describe these measures.

2.9.2 National Accounts consistent GDP

When taking the model GDP measure to the data, we want to be sure that it reflects the corresponding National Accounts concept. While defined based on national accounts methodology, the two identical measures of nominal GDP, are derived starting from the aggregate resource constraint as shown before in equation (136).

Therefore, we define the *nominal GDP in the model*, using the *expenditure approach, in terms of market prices* (by adding the value added tax) as:

$$\begin{aligned} P_t^{GDP} GDP_t = {} & (1+\tau^c) P_t^C C_t + P_t^G G_t + P_t^i \left(I_t + \Delta INV_t\right) + S_t^{ef} P_t^X X_t \\ & - \left[S_t^{ef} P_t^* R_t^{\nu,*} \left(C_t^m + I_t^m + X_t^m\right) + S_t^{RON/USD} P_t^{oil,usd} Oil_t^m \right] + P_t^{GDP} SD_t \end{aligned} \tag{138}$$

where: SD_t represents the statistical discrepancy between GDP and the sum of its components. While for nominal GDP it reflects only the effect of direct seasonal adjustment method used by the Romanian National Institute of Statistics, its presence further in the real GDP measure reflects the lack of additivity of quarterly volumes to real GDP when using chain-linked data. The statistical discrepancy is exogenously determined by assuming that its share in GDP, that is sd_t, follows an AR(1) process.

$$sd_t = \rho^{sd} sd_{t-1} + \left(1 - \rho^{sd}\right) sd + \varepsilon_{sd,t} \tag{139}$$

[24] Although it inherits indirectly the sluggishness of wages.

The equivalent measure of *nominal GDP in the model using the income approach,* is given by:

$$
\begin{aligned}
P_t^{GDP} GDP_t = {} & W_t R_t^f H_t + \omega_k \left(r_t^{DC,k} P_t \right) K_t^{DC} + (1-\omega_k) \left(r_t^{FC,k} P_t \right) K_t^{FC} \\
& + profits_t - monitoring_t - hiring_t - maintenance_t \\
& = P_t^{VA} VA_t + \left(P_t Y_t - \frac{mc_t P_t}{\tau_t^d} \left(Y_t + z_t^+ \phi \right) \right) \\
& + \left(P_t^{oil} - \frac{NMC_t^{m,oil}}{\tau_t^{m,oil}} \right) Oil_t + \left(P_t^c - NMC_t^c \right) C_t + \left(S_t^{ef} P_t^X - \frac{NMC_t^x}{\tau_t^x R_t^x} \right) X_t + \\
& \left(P_t^{m,c} - \frac{NMC_t^{m,c}}{\tau_t^{m,c}} \right) C_t^m + \left(P_t^{m,i} - \frac{NMC_t^{m,i}}{\tau_t^{m,i}} \right) I_t^m + \left(P_t^{m,x} - \frac{NMC_t^{m,x}}{\tau_t^{m,x}} \right) X_t^m - \\
& - \omega_k \left[\mu_{DC} G_t(\bar{\omega}_t^{DC}; \sigma_{t-1}^{DC}) R_t^{k,DC} P_{t-1} P_{k',t-1} \bar{K}_t^{DC} \right] \\
& - (1-\omega_k) \left[\mu_{FC} G_t(\bar{\omega}_t^{FC}; \sigma_{t-1}^{FC}) R_t^{k,FC} P_{t-1} P_{k',t-1} \bar{K}_t^{FC} \right] \\
& - \sum_{j=0}^{N-1} P_t \frac{\kappa z_t^+}{\varphi} \left(\tilde{\nu}_t^j \right)^{\varphi} \left(1 - \int_0^{\bar{a}_t^j} dF(a, \sigma_{a,t}) \right) l_t^j \\
& - P_t^i \left(a^{DC}(u_t^{DC}) \omega_k \bar{K}_t^{DC} + a^{FC}(u_t^{FC}) (1-\omega_k) \bar{K}_t^{FC} \right) + P_t^{GDP} SD_t
\end{aligned} \tag{140}
$$

As it can be observed from the above equation the main source for GDP in the model is represented by the value added by the labor and capital services, complemented by the monopolistic profits of the retailers that aggregate the corresponding goods. It should be also mentioned that given the structure of the model some goods are exposed to multiple markups being applied to them until they reach the final user/demand. That is the case for imported oil, consumption and export goods and intermediate goods used for consumption and exports. Last but not least, the monitoring, hiring and capital utilization costs are extracted from the model GDP in order to match its data equivalent.

2.9.3 The GDP deflator

The GDP equations presented in the previous section define the nominal GDP consistent with the National Accounts methodology. However, neither the real GDP nor the GDP deflator are defined inside the model. Therefore, there is need for an additional equation that pins down the evolution of the GDP deflator. In doing so, we follow de Castro et al. (2011) and define the GDP deflator in such a way that changes in real GDP are computed using constant weights (i.e. changes in prices relative to the GDP deflator do not play any role in the real GDP dynamics).

$$\left(P_t^{GDP}\right)^{1-s^{SD}} = \left((1+\tau^c)P_t^C\right)^{s^C}\left(P_t^G\right)^{s^G}\left(P_t^I\right)^{s^i}\left(S_t^{ef}P_t^X\right)^{s^X}$$
$$\left(S_t^{ef}P_t^*R_t^{\nu,*}\right)^{-\left(s^m-\frac{S^{RON/USD}P^{oil,usd}Oil^m}{P^{GDP}GDP}\right)}\left(S_t^{RON/USD}P_t^{oil,usd}\right)^{-\left(\frac{S^{RON/USD}P^{oil,usd}Oil^m}{P^{GDP}GDP}\right)} \tag{141}$$

where the weights are equal to the corresponding steady state nominal shares of component j in GDP: $s^c = \frac{(1+\tau^c)P^cC}{P^{GDP}GDP}$, $s^g = \frac{P^GG}{P^{GDP}GDP}$, $s^i = \frac{(1+\Delta inv)P^iI}{P^{GDP}GDP}$, $s^x = \frac{P^xXS^{ef}}{P^{GDP}GDP}$, $s^m = \frac{(P^*R^{\nu,*}S^{ef})(C^m+I^m+X^m)+S^{RON/USD}P^{oil,USD}Oil^m}{P^{GDP}GDP}$ and $s^{SD} = \frac{P^{GDP}SD}{P^{GDP}GDP}$.

The corresponding inflation rate is defined as:

$$\pi_t^{GDP} = \frac{P_t^{GDP}}{P_{t-1}^{GDP}} \tag{142}$$

2.10 Net exports, current account, net foreign assets and the risk premium

The share of goods and services trade balance in nominal GDP is computed by dividing the domestic currency value of exports minus the corresponding value of imports by nominal GDP, that is:

$$(NX/GDP)_t = \frac{S_t^{ef}P_t^xX_t - \left[S_t^{ef}P_t^*R_t^{\nu,*}\left(C_t^m + I_t^m + X_t^m\right) + S_t^{RON/USD}P_t^{oil,usd}Oil_t^m\right]}{P_t^{GDP}GDP_t} \tag{143}$$

The current account balance is computed by summing the trade balance with the interest rate payments (net of eventual taxes) on the stock of net foreign assets (these are part of the debit of income balance) and with the transfers balance. The latter component is important for emerging economies as it reflects the usually significant impact of remittances sent by domestic individuals working abroad.

$$\begin{aligned} CA_t &= NX_t \\ &+ \left[\left(R_{t-1}^{EUR}\Phi_{t-1} - 1\right)\frac{S_t^{RON/EUR}}{S_{t-1}^{RON/EUR}} - \tau^{d,FC}\left(\frac{S_t^{RON/EUR}}{S_{t-1}^{RON/EUR}}R_{t-1}^{EUR}\Phi_{t-1} - 1\right)\right](NFA_{t-1}) \\ &+ FTR_t \end{aligned} \tag{144}$$

It should be mentioned that the above equation captures also valuation changes due to exchange rate movements, included here for simplicity in the income balance part of the current account.

The equation describing the evolution *(in domestic currency units)* of current net foreign assets position as a function of net exports and previous, risk adjusted interest rate payments included, is given by:

$$NFA_t = NX_t + FTR_t + \left[R_{t-1}^{EUR} \Phi_{t-1} \frac{S_t^{RON/EUR}}{S_{t-1}^{RON/EUR}} - \tau^{d,FC} \left(\frac{S_t^{RON/EUR}}{S_{t-1}^{RON/EUR}} R_{t-1}^{EUR} \Phi_{t-1} - 1 \right) \right] NFA_{t-1} \tag{145}$$

with the stock of net foreign assets being defined as:

$$NFA_t = -(1-\omega_k) S_t^{RON/EUR} FB_{t+1} \tag{146}$$

which can be rewritten in terms of stationarized variables$\left(nfa_t = \frac{NFA_t}{P_t z_t^+} \right)$ as:

$$nfa_t = -(1-\omega_k) \frac{S_t^{RON/EUR} FB_{t+1}}{P_t z_t^+} \tag{147}$$

As it can be observed from the above relation, in this model, the economy is in fact a net debtor to the rest of the world, as it accumulates liabilities given by the deposits in the foreign currency banks. Given the National Accounts identity according to which the current account represents the variation in net foreign assets (adjusted with exchange rate variations), an equivalent formula for the current account is given by:

$$CA_t = NFA_t - \frac{S_t^{RON/EUR}}{S_{t-1}^{RON/EUR}} NFA_{t-1} \tag{148}$$

The foreign transfers are exogenously determined by assuming that its (domestic currency) share in nominal GDP, that is $ftr_t = \frac{FTR_t}{P_t^{GDP} GDP_t}$, follows an AR(1) process.

$$ftr_t = \rho^{ftr} ftr_{t-1} + \left(1 - \rho^{ftr}\right) ftr + \varepsilon_{ftr,t} \tag{149}$$

Several notes should be made before proceeding further. First, as mentioned before, the currency structure of the current account flows takes into account that external trade in goods and services takes place both in EUR and USD (with ω_q being the weight of external trade made by domestic agents in EUR and $1-\omega_q$ in USD), while financial flows take place exclusively in EUR. Let's assume for example that the USD appreciates with respect to the EUR, while the RON/EUR exchange rate, the only one determined on the domestic market, remains unchanged. As a result, the domestic currency, RON, depreciates with respect to USD. In our model, *ceteris paribus*, there is no effect on financial flows as they take place in EUR, while there is a net positive effect on external trade due to the part of it that takes place in USD.

Second, given that in equilibrium the economy accumulates foreign liabilities, the steady state stationarized version of the equation describing the evolution of net foreign assets, (145), implies a positive, and usually small, balance of trade in goods and services and foreign transfers, i.e. $NX_t + FTR_t$[25]. Given that over the period analyzed the transfers' balance

[25] In the regular small open economy model, in steady state, balanced trade is usually assumed, resulting in zero NFA position in equilibrium as a single solution. In this model, the amount of foreign loans $((1-\omega_k) S_t^{RON/EUR} FB_{t+1})$ is positive in equilibrium. If zero aggregate NFA position is desired (and implicitly 0 balance in terms of trade in goods and services and foreign transfers), then domestic households will have to save in equilibrium in order to meet the entire demand of foreign currency deposits.

was positive and significant in size (around 3.5% of GDP), we are able to accommodate the existence of a deficit in the trade balance in equilibrium in line with the existing evidence[26].

2.10.1 The risk premium

When borrowing in foreign currency, banks that provide entrepreneurs with foreign currency loans have to pay a risk premium adjusted interest rate, a cost that is transferred further towards the corresponding entrepreneurs.

While from a technical point of view the presence of a risk premium adjusted interest rate is necessary to have a unique steady state value of net foreign assets that is independent of its initial position (Schmitt-Grohe and Uribe (2003)), its exact form might differ. Changes are usually motivated by empirical evidence that suggests delayed overshooting of the exchange rate to a monetary policy shock. Christiano et al. (2011) modifies the risk premium specification by adding the interest rate differential in order to generate a delayed overshooting of the exchange rate to a monetary policy shock and to also match the empirical evidence for Sweden according to which there is a negative covariance between the expected exchange rate changes and interest rate differential. Another form is the one introduced by Adolfson et al. (2007a), with the expected change in the exchange rate being part of the risk premium. However, the evidence in Bansal and Dahlquist (2000) suggests that the delayed overshooting phenomenon might not be present for emerging economies.

While we formally tested alternative versions of the risk premium specification (e.g. as in Christiano et al. (2011) or Adolfson et al. (2007a)), we chose the classical form, as suggested by Schmitt-Grohe and Uribe (2003), according to which the risk premium varies negatively with the net foreign assets of the economy:

$$\Phi_t(nfa_t, \tilde{\phi}) = \exp\left[-\phi_{nfa}\left(nfa_t - nfa\right) + \tilde{\phi}_t\right] \tag{150}$$

where $\Phi_t' < 0$, $\Phi_t(0,0) = 1, \phi_{nfa} > 0$ and $\tilde{\phi}_t$ is an AR(1) shock to the risk premium.

[26]In steady state, the retrieved deficit in the trade balance is close, but slightly smaller in absolute value, than the surplus in the transfers' balance, given the existence of net foreign liabilities in equilibrium. Therefore, given that the sum of the trade and transfers balances is close to 0 in equilibrium, the current account deficit is mostly determined by the debit part of the income balance (interest rate payments on foreign debt), a fact that is not necessarily supported by data evidence.

3 Measurement equations and model-consistent filtering

The model's balanced growth path is ensured by the z_t^+ aggregate trend, which is a combination of investment-specific and neutral technologies (see subsection 3.3 below). However, for emerging economies the observed variables usually display specific growth rates rendering the balanced growth approach, in either nominal or real terms, inconsistent with actual data. In order to implement imbalanced trends within the model we follow Argov et al. (2012) approach for model-consistent filtering used in building MOISE, the DSGE model for the Israeli economy. The multivariate procedure doesn't require any pre-filtering of the data (e.g. demeaning), while the excess trends of each variable with respect to the model-implied common trend are removed when estimating the model in a consistent way. The excess trends are specified when linking endogenous and observed variables. From a technical point of view, these components can be also interpreted as non-zero, auto-correlated measurement errors. For those observed variables with no excess trends, we still allow for standard white noise measurement errors.

3.1 Domestic variables

Inflation target measurement equation and the corresponding excess trend are given by:

$$\bar{\pi}_t^{c,data} - EXT_t^{\bar{\pi}^c} = 400 \log \bar{\pi}_t^c \tag{151}$$

$$EXT_t^{\bar{\pi}^c} = (1 - \rho^{\bar{\pi}^c,EXT})(\mu^{\bar{\pi}^c} - \bar{\pi}) + \rho^{\bar{\pi}^c,EXT} EXT_{t-1}^{\bar{\pi}^c} + \varepsilon_t^{\bar{\pi}^c,EXT} \tag{152}$$

Note that the excess trend follows a first order auto-regressive process, determining a steady state value equal to the deviation of sample mean of inflation rate target ($\mu^{\bar{\pi}^c}$) from the model implied steady state ($\bar{\pi}$). In what follows, $\varepsilon_t^{\bullet,EXT}$ have the interpretation of disturbances to the excess trend components (or from a technical point of view, innovations in the measurement errors).

Excess trends of the other observed inflation rates over the model implied ones are specified as the *sum of inflation target excess trend and a specific excess trend, with the latter explaining the difference between data mean of a certain variable and sample mean of inflation rate target.*

The GDP deflator inflation is linked to its model counterpart using the following specification:

$$\pi_t^{GDP,data} - EXT_t^{\bar{\pi}^c} - EXT_t^{\pi^{GDP}} = 400 \log \pi_t^{GDP} \tag{153}$$

$$EXT_t^{\pi^{GDP}} = (1 - \rho^{\pi^{GDP},EXT})(\mu^{\pi^{GDP}} - \mu^{\bar{\pi}^c}) + \rho^{\pi^{GDP},EXT} EXT_{t-1}^{\pi^{GDP}} + \varepsilon_t^{\pi^{GDP},EXT} \tag{154}$$

The trend of GDP deflator inflation has two components, namely the inflation target excess trend in (152) and a specific term in (154), the latter given by the difference between its data mean and the inflation target mean in the data ($\mu^{\pi^{GDP}} - \mu^{\bar{\pi}^c}$). The corresponding equations for the remaining price indices are similar:

$$\pi_t^{j,data} - EXT_t^{\bar{\pi}^c} - EXT_t^{\pi^j} = 400 \log \pi_t^j \tag{155}$$

$$EXT_t^{\pi^j} = (1 - \rho^{\pi^j,EXT})(\mu^{\pi^j} - \mu^{\bar{\pi}^c}) + \rho^{\pi^j,EXT} EXT_{t-1}^{\pi^j} + \varepsilon_t^{\pi^j,EXT} \tag{156}$$

where $j \in \{c, core1, adm, m, x, i\}$. There are three exceptions form the expressions above, given by some particularities described below. First, for the administered prices ($j \in \{adm\}$) we compute the excess trend as a residual given the total consumption and CORE1 inflation rates' specific trends:

$$EXT_t^{\pi^{adm}} = \frac{EXT_t^{\pi^c} - (1 - \omega_{adm}) EXT_t^{\pi^{core1}}}{\omega_{adm}} + \varepsilon_t^{\pi^{adm},EXT} \tag{157}$$

Second, inflation rate of exported goods ($j \in \{x\}$) measurement equation is slightly different given the local currency pricing concept used in the model (the export prices in the model are expressed in foreign currency, while the deflator measured in the data is expressed in domestic currency):

$$\pi_t^{x,data} - EXT_t^{\bar{\pi}^c} - EXT_t^{\pi^x} = 400 \log \left(\pi_t^x \frac{S_t^{ef}}{S_{t-1}^{ef}} \right) \tag{158}$$

Third, the price inflation of the investment goods purchased to increase the stock of physical capital (the gross fixed capital formation component of GDP, $j \in \{i\}$) is affected by the presence of the investment specific trend[27]:

$$EXT_t^{\pi^i} = (1 - \rho^{\pi^i,EXT})(\mu^{\pi^i} - \mu^{\bar{\pi}^c} - 400 \log \mu_\psi) + \rho^{\pi^i,EXT} EXT_{t-1}^{\pi^i} + \varepsilon_t^{\pi^i,EXT} \tag{159}$$

The measurement equations and specific trends for the real quantities are defined equivalently. The common trend determined by the balanced growth path, $\mu_{z^+,t}$, is linked to the real GDP data:

$$\Delta \log GDP_t^{data} = 100(\log \mu_{z^+,t} + \Delta \log GDP_t) + \varepsilon_t^{y,ME} \tag{160}$$

The other GDP components contain specific excess trends above or below the GDP trend $\mu_{z^+,t}$. The specific trends are modeled as AR(1) processes with the equilibria calibrated at the deviation of component's mean growth rate (μ^j) from that of the real GDP (μ_{z^+}). Since investment volume is also affected by the specific component $\mu_{\psi,t}$, its measurement and excess trend equations are:

$$\Delta \log I_t^{data} - EXT_t^i = 100(\log(\mu_{z^+,t}\mu_{\psi,t}) + \Delta \log i_t) \tag{161}$$

[27] The unit root (with drift) shock, ψ_t, that captures the decline in the relative price of investment goods might make the use of the excess trend concept for the investment volume and inflation rate redundant when taking the model to the data. This is an aspect that necessitates care when estimation is done.

$$EXT_t^i = (1-\rho^{i,EXT})(\mu^i - 100\log(\mu_{z+}\mu_\psi)) + \rho^{i,EXT}EXT_{t-1}^i + \varepsilon_t^{i,EXT} \tag{162}$$

For the remaining components the corresponding relations are given by:

$$\Delta\log J_t^{data} - EXT_t^j = 100(\log\mu_{z+,t} + \Delta\log j_t) \tag{163}$$

$$EXT_t^j = (1-\rho^{j,EXT})(\mu^j - 100\log\mu_{z+}) + \rho^{j,EXT}EXT_{t-1}^j + \varepsilon_t^{j,EXT} \tag{164}$$

where $j \in \{c, x, m, g\}$. Note that the specific trend of imports is common for all three types of imported goods and also for the oil imports, since in terms of volumes we observe only aggregate imports. The only exception to the above formulas is related to the excess trend of government consumption (EXT_t^g), which is calculated as a residual such as the weighted sum of excess trends of GDP components is zero, similar to Argov et al. (2012):

$$s^g EXT_t^g + s^c EXT_t^c + s^i(EXT_t^i + 100\log\mu_{\psi,t}) + s^x EXT_t^x - s^m EXT_t^m = 0 \tag{165}$$

where the weights are equal to the corresponding steady state nominal shares of component j in GDP, as in equation (141).

The remaining measurement equations don't contain any specific trends and are listed below. Observed data for statistical discrepancy share in GDP, change in inventories share in gross fixed capital formation and foreign transfers ratio to GDP are connected to their model counterparts as follows:

$$j_t^{data} = 100 j_t + \varepsilon_t^{j,ME} \tag{166}$$

where $j \in \{sd, \Delta inv, \Delta\widehat{ft}\}$.

The measurement equations for the financial variables, that are all demeaned, are:

$$R_t^{data} = 400(R_t - R) \tag{167}$$

$$\Delta\log Spread_t^{DC,data} = 100\Delta\log spread_t^{DC} + \varepsilon_t^{spread^{DC},ME} \tag{168}$$

$$\Delta\log Spread_t^{FC,data} = 100\Delta\log spread_t^{FC} + \varepsilon_t^{spread^{FC},ME} \tag{169}$$

$$\Delta\log S_t^{RON/EUR,data} = 100\log(s_t^{RON/EUR} - s^{RON/EUR}) + \varepsilon_t^{s^{RON/EUR},ME} \tag{170}$$

where the model implied equations for the spreads are defined in (82) and (83) and $s_t^{RON/EUR}$ represents the log variation in the RON/EUR nominal exchange rate. Note that the only variable for which we don't use any measurement error is the monetary policy interest rate.

As for hours worked and unemployment rate, we use demeaned first difference of the observed data:

$$\Delta H_t^{data} = 100\Delta \log \left(\sum_{j=0}^{N-1} \chi_t^j \left(1 - \int_0^{\bar{a}_t^j} dF(a, \sigma_{a,t}) \right) l_t^j \right) + \varepsilon_t^{H,ME} \tag{171}$$

$$\Delta \log U_t^{data} = 100\Delta \log (1 - L_t) + \varepsilon_t^{U,ME} \tag{172}$$

The demeaned observed variation in the nominal wage is linked to the employment-weighted average Nash bargained wage across the cohorts $\omega_t^{avg} = \frac{1}{L} \sum_{j=0}^{N-1} l_t^j G_{t-j,t} \omega_{t-j} \bar{\omega}_{t-j}$:

$$\Delta \log W_t^{data} = 100(\log \mu_{z^+,t} - \log \mu_{z^+} + \bar{\pi}_t^c - \bar{\pi}^c + \Delta \log \omega_t^{avg}) + \varepsilon_t^{W,ME} \tag{173}$$

There are additional (demeaned) data series related to financial and labor markets one can use as observables when estimation is performed. The data we are referring to is (demeaned): change in vacancies, change in real net worth, change in the volume of new loans to non-financial corporations in domestic currency expressed in real terms and the volume of new loans to non-financial corporations in foreign currency, expressed in domestic currency, real terms[28].

$$\Delta \log Vacancy_t^{data} = 100\Delta \log (\nu_t) + \varepsilon_t^{\nu,ME} \tag{174}$$

$$\Delta \log N_t^{data} = 100(\log \mu_{z^+,t} - \log \mu_{z^+} + \Delta \log n_t) + \varepsilon_t^{n,ME} \tag{175}$$

$$\Delta \log L_t^{DC,data} = 100(\log \mu_{z^+,t} - \log \mu_{z^+} + \omega_k \Delta \log L_t^{DC}) + \varepsilon_t^{L^{DC},ME} \tag{176}$$

$$\Delta \log L_t^{FC,data} = 100(\log \mu_{z^+,t} - \log \mu_{z^+} + (1 - \omega_k) \Delta \log L_t^{FC}) + \varepsilon_t^{L^{FC},ME} \tag{177}$$

where ν_t represents the model measure of vacancies across cohorts. For a list of actual observable variables used in estimation see table 1.

3.2 External variables

Taking into account both the exogeneity of the external sector block relative to the domestic one, and also the fact that the specific trends approach magnifies the already relatively high dimension of the estimated parameters space in the context of a relatively short data sample, we choose to estimate the external sector outside the main model. Taking into account that in the data foreign variables have different growth rates than the model-implied ones, we extend the specific trends approach to these variables also, including them in the estimation of the external sector.

[28] In choosing the model counterpart of new loans to non-financial corporations, only the loans demanded by entrepreneurs are considered. An alternative version would add to the loans taken by entrepreneurs the working capital loans taken by intermediate producers and exporters (in domestic currency), while those taken by importers of consumption, investment and export goods would be added to the volume of loans in foreign currency.

Euro area and US inflation and interest rates measurement and excess trend equations are:

$$\pi_t^{j,data} - EXT_t^{\pi^j} = 400\pi_t^j \tag{178}$$

$$EXT_t^{\pi^j} = (1-\rho^{\pi^j,EXT})(400\log\pi^* - \mu^{\pi^j}) + \rho^{\pi^j,EXT} EXT_{t-1}^{\pi^j} + \varepsilon_t^{\pi^j,EXT} \tag{179}$$

$$R_t^{j,data} - EXT_t^{R^j} = 400(R_t^j - 1) \tag{180}$$

$$EXT_t^{R^j} = (1-\rho^{R^j,EXT})(400R^* - \mu^{R^j} - 400) + \rho^{R^j,EXT} EXT_{t-1}^{R^j} + \varepsilon_t^{R^j,EXT} \tag{181}$$

where $j \in \{EUR, US\}$. Again, the excess trends control for larger model inferred steady states (π^* and R^*; these are equal for both foreign economies) than sample data averages (μ^{π^j} and μ^{R^j}). The nominal USD/EUR exchange rate and price of oil in USD are linked to the model with:

$$\Delta\log S_t^{USD/EUR,data} - EXT_t^{S^{USD/EUR}} = 100\Delta\log\left(\frac{S_t^{USD/EUR}}{S_{t-1}^{USD/EUR}}\right) = 100\log s_t^{USD/EUR} \tag{182}$$

$$EXT_t^{S^{USD/EUR}} = (1-\rho^{S^{USD/EUR},EXT})\mu^{S^{USD/EUR}} + \rho^{S^{USD/EUR},EXT} EXT_t^{S^{USD/EUR}} + \varepsilon_t^{S^{USD/EUR},EXT} \tag{183}$$

$$\pi_t^{oil,USD,data} - EXT_t^{\pi_t^{oil,USD}} = 400\log\pi_t^{oil,USD} \tag{184}$$

$$EXT_t^{\pi^{oil,USD}} = (1-\rho^{\pi^{oil,USD},EXT})(\mu^{\pi^{oil,USD}} - 400\log\pi^*) + \rho^{\pi^{oil,USD},EXT} EXT_{t-1}^{\pi^{oil,USD}} + \varepsilon_t^{\pi^{oil,USD},EXT} \tag{185}$$

When dealing with the output of the foreign economies (Euro area and US, with the latter as a proxy for the rest of the world) we use a different approach. When (separately) estimating the external sector, output gaps are needed. Therefore, we use the (quarterly interpolated) output gaps for Euro area and US real GDP measures, as they resulted from the European Commission Autumn 2014 regular forecast exercise. The measurement equation for external real GDP used in the estimation of the foreign sector outside the main model is:

$$Y_t^{j,data,gap} = y_t^{j,gap} + \varepsilon_t^{y^j,ME} \tag{186}$$

where $j \in \{EUR, US\}$.

3.3 Scaling and defining variables

The scaling of variables in the presence of one neutral technology shock and an unit-root investment specific shock is described below. Similar to Christiano et al. (2011) the neutral technology shock is z_t and its growth rate is $\mu_{z,t}$:

$$\mu_{z,t} = \frac{z_t}{z_{t-1}} \tag{187}$$

There is also one specific investment technology shock, ψ_t, an unit root (with drift) shock for investment used in building physical capital bought by each type of entrepreneurs.

The aggregate trend, z_t^+, is defined as the following combination of neutral and investment technology shocks:

$$z_t^+ = z_t \left(\psi_t\right)^{\frac{\alpha}{1-\alpha}} \tag{188}$$

$$\mu_{z^+,t} = \mu_{z,t} \left(\mu_{\psi,t}\right)^{\frac{\alpha}{1-\alpha}} \tag{189}$$

Given the above, the scaling of variables (mostly those affected by the introduction of an additional investment specific technology trend) is presented below. For those not mentioned, the scaling is similar with that in Christiano et al. (2011).

$$\begin{aligned}
k_{t+1}^{DC} &= \frac{K_{t+1}^{DC}}{z_t^+\psi_t},\ \bar{k}_{t+1}^{DC} = \frac{\bar{K}_{t+1}^{DC}}{z_t^+\psi_t},\ k_{t+1}^{FC} = \frac{K_{t+1}^{FC}}{z_t^+\psi_t},\ \bar{k}_{t+1}^{FC} = \frac{\bar{K}_{t+1}^{FC}}{z_t^+\psi_t},\ y_t = \frac{Y_t}{z_t^+} \\
i_t &= \frac{I_t}{z_t^+\psi_t},\ i_t^d = \frac{I_t^d}{z_t^+},\ i_t^m = \frac{I_t^m}{z_t^+},\ p_t^i = \frac{\psi_t P_t^i}{P_t} \\
\bar{r}_{r,t}^{k,DC} &= r_t^{k,DC}\psi_t = \frac{R_t^{k,DC}}{\frac{P_t}{\psi_t}},\ \bar{r}_{r,t}^{k,FC} = r_t^{k,FC}\psi_t = \frac{R_t^{k,FC}}{\frac{P_t}{\psi_t}},\ p_{k',t} = \psi_t P_{k',t}.
\end{aligned}$$

Given that the foreign output enters the model in terms of gaps, there is no need in further stationarizing it.

4 Estimation

The model is estimated[29] using endogenous priors procedure as proposed by Christiano et al. (2011). However, we adapt it such that we match the chosen moments for only a subset of the observed variables. We estimate the external sector block of the model exogenously, also using the endogenous priors methodology mentioned above. Implicitly, when estimating the domestic block of the model, while we include the external data series as observable, we exclude their standard deviations from the set of moments to be matched. The estimation results for the foreign sector are presented in the Appendix 6.2.

4.1 Data used in estimation

We use 29 observable variables[30] for estimating the model, a number of series that is somehow larger than in other DSGE models, but which is necessary to properly capture specific features of the theoretical structure of the model, like currency substitution, CPI inflation rate disaggregation, enriched foreign economy sector, etc. It is also important to mention that 8 out these series are related to the exogenously estimated external sector (in addition, these cover a longer period, i.e. 1995Q2-2014Q3). The (domestic economy) dataset covers 2005Q3-2014Q3 period and is presented and described in table 1 below, and plotted in figure 5 (inflation rate target is not presented).

The choice for using such a short time span is motivated by several facts, specific in general for emerging economies: the '97-'99 crisis and the extreme consequences on the Romanian economy, still relatively high values of inflation rate, lack of data (e.g. on interest rate spreads) and/or structural breaks for several series in early 2000s, and different monetary policy regimes. Regarding the latter aspect, the sample under analysis includes only *de facto* inflation targeting regime that was implemented since the second part of 2005.

The variables display significant differences in means, rendering balanced growth path framework unsuitable. We overcome this issue using excess trends following Argov et al. (2012), as described in a previous section.

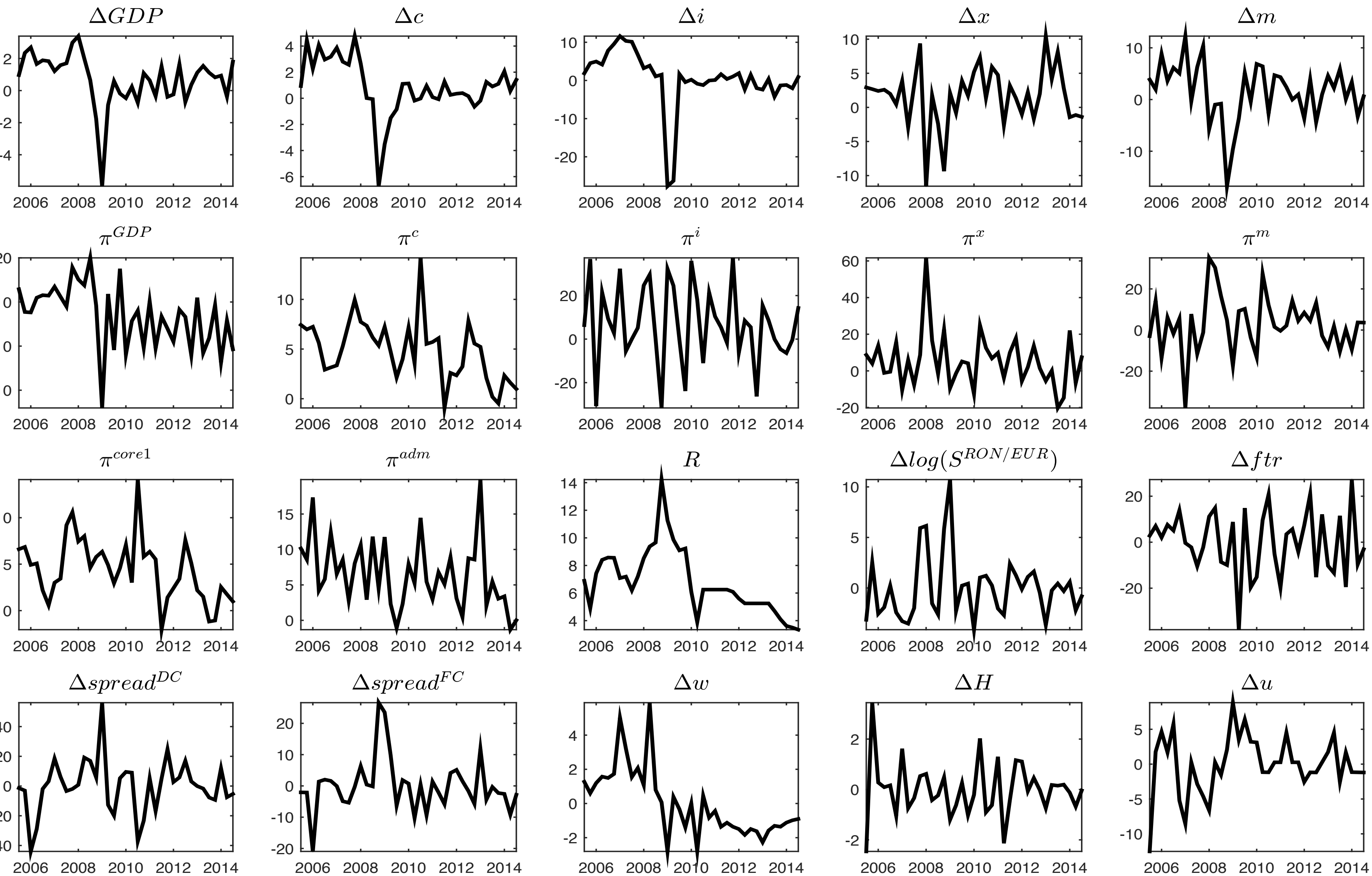
[29] In estimating the model (a substantialy modified version of) the code package of Christiano et al. (2011) was used as available at: http://www.sciencedirect.com/science/article/pii/S0165188911001710.

[30] Data as available on January 14, 2015.

Table 1: *Series used in estimation, 2005Q3-2014Q3*

	Description	*Details*
Quarterly annualized rate		
π_t	Domestic inflation	GDP deflator
π_t^c	Consumer prices inflation	CPI inflation
π_t^{core1}	CORE1 inflation	CORE1 inflation
π_t^{adm}	Administered prices inflation	Administered prices inflation
π_t^i	Investment inflation	GFCF deflator
π_t^x	Exports inflation	Export deflator
π_t^m	Imports inflation	Import deflator
$\bar{\pi}_t^c$	Inflation target	Inflation target
R_t	Nominal interest rate	Monetary policy interest rate
Per capita logged first difference		
Δy_t	GDP growth rate	Gross Domestic Product
Δc_t	Private consumption growth rate	HH and NPISH final consumption expenditure
Δi_t	Investment growth rate	Gross fixed capital formation (GFKF)
Δx_t	Exports growth rate	Exports, goods and services
Δm_t	Imports growth rate	Imports, goods and services
Demeaned, per capita logged first difference		
ΔH_t	Hours worked	Average weekly hours worked
ΔW_t	Nominal wages	Nominal wages, private sector
Demeaned, logged first difference		
$\Delta S_t^{RON/EUR}$	Nominal RON/EUR exchange rate	Nominal RON/EUR exchange rate
Δu_t	Unemployment rate	15-74 years
Demeaned, first difference		
$\Delta spread_t^j$	Corporate interest rate spreads	Difference between the interest rate on new loans to NFC in RON/EUR and interbank interest rate.
Demeaned, first difference, % of nominal GDP		
ftr_t	Foreign transfers, balance	Balance of private foreign transfers, current account

Figure 5: *Observable series as used in estimation, 2005Q3-2014Q3*



4.2 Calibrated parameters

4.2.1 Core domestic model

A number of parameters are calibrated, being kept fixed throughout the estimation. Table 2 displays the values for these parameters. Moreover, similar to Christiano et al. (2011), we choose to exactly match seven observed ratios and consequently recalibrate the corresponding parameters for each draw throughout estimation. These moments and the corresponding parameters at their posterior mean values are displayed in table 3.

The steady state growth rate of aggregate technology (μ_{z^+}) is set at 0.7% (approx. 2.8% in annual terms) to match the average per capita real GDP growth rate in the sample. It represents a weighted measure of investment specific and neutral technology growth rates. However, we chose to set the steady state growth rate of investment specific technology (μ_ψ) to 0%. Therefore, economic growth in our core model is attributable to the growth rate of neutral technology (μ_z) only. There are several reasons for setting the steady state growth rate of investment specific technology to 0%. First, in the data vintage we use in estimation there is no support for a positive contribution on growth coming from the investment specific technology. Using relative prices to recover it, the corresponding growth rate is 0%, while in terms of volumes, the average (quarterly) per capita growth rate of gross fixed capital formation, our proxy for investment in the model, is lower than the corresponding GDP measure (i.e. 0.5% versus 0.7%). Second, as detailed in section 4.4, there are sizable revisions across different vintages of quarterly seasonally adjusted national accounts data. This is the case particularly for investment prices, as measured by the gross fixed capital formation deflator[31].

Given the aggregate growth rate of economy in the steady state, the discount factor ($\beta = 0.9963$) and the domestic currency deposits' tax rate ($= 0$) are calibrated to match in steady state the sample average interest rate. While we allow for a variable inflation target, the steady state value of inflation target ($\bar{\pi}$) is set to 2.5% in annual terms, i.e. the stationary target adopted by the NBR since 2013.

Data on the annual values of the implicit tax rates on consumption and labor over the 2005-2012 period are provided by Eurostat (2014) for each EU country in the yearly report *Taxation Trends in the European Union*. This helps in calibrating the other tax rates at their mean implicit values in place for the 2005-2012 period[32], that is: 18.05% for the

[31] In estimating the model of Christiano et al. (2011) for Romania, Copaciu (2012), using data as available on April 11, 2012, for the 2003Q1-2011Q4 period, sets the steady state growth rate of investment specific technology (μ_ψ) at 0.47% (approx. 1.88% in annual terms) as a measure resulting from the evolution of relative prices. As a result, the part of economic growth attributable to the technological improvements specific to the investments goods producing sector is around 40%, similar with the one found by Justiniano et al. (2011) for the US economy over a longer time period (i.e. 1983-2008). Besides slightly different sample, these differences point out to the high importance of data revisions.

[32] One could argue that variations in the tax rates should be allowed, given the fiscal related changes that occurred during the sample. There are several reasons why we opted for working with constant taxes. First, given that we do not observe any fiscal related variables, the impact of tax rates is limited. Second, the Ricardian nature of the model, reinforces their limited impact. Third, the change in the VAT rate occurred at the end of our sample. Last but not least, the small sample and the already high number of parameters that are estimated are additional reasons to work with constant tax rates.

consumption tax rate (τ^c) and 29.4% for the labor tax rate $\left(\frac{1-\tau^y}{1+\tau^w}\right)$ [33].

The share of capital services in the production function of domestic intermediate goods, α, is set at a higher value relative to those usually assumed in the literature, namely 0.55. There are several reasons that justify this choice.

First, over the chosen sample, the national accounts data point towards an average share of labor, that is $(1-\alpha)$, of 0.55, with an average of 0.5 starting with 2010. Second, values of α above 0.4 are not uncommon for DSGE models (usually without financial frictions) developed for both emerging and advanced economies. For example, de Castro et al. (2011) use a capital income share in GDP of 0.45 for Brazil, Gelain and Kulikov (2011) use a value of 0.46 for Estonia, 0.5 is used by Zeman and Senaj (2009) for Slovakia, while in case of Lithuania, the similar measure used is 0.5 (Pusinskaite and Vetlov (2013)). For Finland, Kilponen and Ripatti (2006) use a weight of approximately 0.45, while 0.48 is used by Lafourcade and de Wind (2012) in case of Netherlands.

Last but not least, a higher than usual value is chosen such that, while compensating for the existence of a relatively large and positive external finance premium, to accommodate a prior ratio of capital to annual GDP of around 1.5 in nominal terms. The equivalent measure in real terms is 2.75. The capital to GDP ratio, when expressed in nominal terms, is relatively lower compared with the ones estimated for the Romanian economy. Gălăţescu et al. (2007) and Altar et al. (2009) find values around 2.3 for the capital to output ratio. However, given the lack of reliable capital stock data and that the methodologies employed assume a rather arbitrary capital to output ratio at the beginning of the transition period, one could argue that the starting values are relatively high given the obsolete value of most of the capital stock inherited from the socialist period. Moreover, in the above mentioned papers, there is no specific role for the price of capital. Therefore, comparing the ratios in real terms would be more appropriate. A regular estimate of the capital to output ratio for Romania is provided by the European Commission in its regular forecasting exercises. However, also in this case there is heterogeneity in the 2005-2014 sample average capital to output ratio across forecasting rounds. For example, while the average for the Winter 2015 round is 2, the similar figure in the Autumn 2013 forecasting exercise was 1.8.

Following the approach of Bussiere et al. (2011), the import shares in the production of final goods are recovered from the Eurostat Input-Output tables available for 2005, 2006, 2008 and 2010, incorporating both the direct and indirect impact of imports in the production of final demand goods, but excluding the share of imported oil/energy products. The calibrated values represent the average for the years data is available, namely: 23.2% for ω_c, 46.5% for ω_i and 28.1% for ω_x. The share of imported oil related products in the gross value added is set at 2%, a value similar with the one used by Zeman and Senaj (2009) for Slovakia, but higher than the 1% share used by Cuche-Curti et al. (2009) for Switzerland. In terms of currency composition of exports and imports, we set ω_q to 72.6%, the average weight of trade transactions in goods and services taking place in EUR for the 2006-2014 period. We set the share of administered prices goods in total CPI basket, that is ω_{adm} to 18%, the average value for the sample period considered. Similar to de Castro et al. (2011), we set χ_{adm}, one of the administered prices indexation factor parameters, to 0.8.

[33] Assuming a 16% personal income tax rate (τ^y), in place for our entire sample, results in a payroll tax rate of around 19%. The tax rate on capital, τ^k, is set to 0 in the current estimated version of the model.

Several parameters are calibrated at similar values with those usually assumed in the literature (i.e. Christiano et al. (2011), Adolfson et al. (2007a)): the elasticity of country risk premium to the NFA position ($\tilde{\phi}_{nfa}$) is set at 0.01; most of the price markups λ_j are set to 1.2, with $j \in \{d, mx, mc, mi, moil\}$, with the exception of λ_x and λ_c which are each set to 1.05, in order to avoid the impact of multiple markups; we assume full indexation of real wages to the real growth trend ($\vartheta_w = 1$), while allowing for prices to be indexed to a combination of lagged inflation rate and central bank's inflation target.

The *quarterly values* of the steady state bankruptcy rates, $F(\bar{\omega}_{DC})$ and $F(\bar{\omega}_{FC})$, are set to the sample average value for non-financial corporations with most of the loans in either domestic or foreign currency, that is 1.63% and 1.77% respectively[34]. As for transfers to entrepreneurs, $\frac{W_e^j}{P^{VA}VA}$, they are assumed to represent 0.05% of nominal gross value added for each category $j \in \{DC, FC\}$.

The unemployment rate in steady state $(1-L)$ is set at the average value for the 2005Q3-2014Q3 period, namely 6.7%, being close to the average NAIRU value for the same period, as determined by the European Commission in its Winter 2015 forecasting round, namely 6.8%. Consistent with the empirical evidence presented in Copaciu et al. (2010) and Iordache and Pandioniu (2015) for Romania, wages are assumed to be renegotiated with annual frequency ($N = 4$). Similar to Christiano et al. (2011), hiring costs are assumed to be quadratic (i.e. $\varphi = 2$).

The unemployment share in the matching technology, σ, is set to 0.5 implying an equal share in the production for matches for the number of unemployed and vacancies, in accordance with the general evidence presented in Petrongolo and Pissarides (2001), but also with the one specific for Romania as presented in European Commission (2013). The level parameter in the matching function, σ_m, is set to 0.482, while we follow Christiano et al. (2011) and assume hiring costs instead of search costs (i.e. $\iota = 1$). We set the parameter reflecting the exogenous survival rate of a match, ρ, to 0.982. At the prior steady state, all these lead to a probability of filling a vacancy in a given quarter of around 0.83, a vacancy rate of around 2.2%[35] and an average duration of unemployment of around 11 months. Regarding the latter, the up to date evidence for Romania is, to our knowledge, rather scarce and/or not covering the analyzed period. According to Earle and Pauna (1996), unemployment duration in Romania in 1993 was 8.6 months, while Ciuca and Matei (2011) report unemployment duration being around 6 months for a set of Romanian counties over the 2007-2009 period. However, both the above estimates are less informative when one considers the associated high standard errors. Eurostat data regarding all unemployment spells for Romania for the analyzed period, points towards a minimum unemployment duration of around 11 months. Hobijn and Sahin (2009), investigating job finding and separation rates for OECD countries, find similar, or slightly higher than 11 months, unemployment durations for Czech Republic, Hungary and Poland.

We set $\eta_{g,nom}$, the weight of government consumption goods in gross value added in

[34]We thank our colleagues from the Financial Stability Department for providing the timeseries for bankruptcy rates across companies with most of the loans in either domestic or foreign currency.

[35]This is slightly higher than the empirical counterpart for the analized period, that is 1.1%, matching mainly the 1.9% average vacancy rate for the period up to the crisis (until the end of 2008).

nominal terms, in order to match the average share, in nominal terms, of government consumption in GDP during the analyzed period (i.e. 16%), while $\eta_{g,real}$ is calibrated in steady state close to its empirical counterpart in real terms. The relative price of government consumption goods to gross value added is recovered as $\eta_{g,nom}/\eta_{g,real}$. As we do not observe government expenditures, we set the persistence coefficient, ρ_g, in the AR(1) equation describing their evolution to 0.5, and the standard deviation of the corresponding shock, σ_g, to 0.3. The remaining steady state shares that help us to match the National Accounts concepts are calibrated at their historical averages, in nominal terms: the share of statistical discrepancy to GDP, sd, to 1%; the share of change in inventories in gross fixed capital formation, Δinv, to -1.4%. As for the latter, we set the persistence coefficient, $\rho^{\Delta inv}$ in the AR(1) equation describing their evolution to 0.5, and the standard deviation of the corresponding shock, $\sigma_{\Delta inv}$, to 0.3. Also, the share of net foreign (private) transfers to GDP, ftr, is set at its historical average over the analyzed period, that is 3%.

Similar to Christiano et al. (2011), we chose 6 observables to be matched exactly throughout estimation, by sequentially recalibrating an equal number of parameters (see table 3):

- the steady state level of the real effective exchange rate, $\tilde{\varphi}$, to match the share of nominal exports in nominal GDP;
- the parameter scaling the disutility of labor, A_L, to match the average fraction of time spent working by an individual[36];
- the depreciation rate of capital to match the share of nominal gross fixed capital formation, our proxy for investment, in nominal GDP;
- the entrepreneurial survival rates, γ^{DC} and γ^{FC}, in order to match the average, over the analyzed period, equity to assets ratios for entrepreneurs borrowing mostly in domestic or foreign currency, respectively[37];
- the parameter controlling the share of entrepreneurs borrowing in domestic currency, ω_k, to match the average, over the analyzed period, ratio of foreign to domestic currency denominated new loans to non-financial corporations;
- the steady state USD price of oil, in order to match the share of oil in GDP, in nominal terms.

The posterior mean values of the above mentioned parameters are presented in table 3.

[36] The fraction of time spent working is computed as: $\frac{\text{Average nr.of weekly hours of work*Nr. of weeks in a quarter}}{\text{Max. nr.of weekly hours of work (i.e. 7*14) *Nr. of weeks in a quarter}} * \frac{\text{Total employed persons}}{\text{Total population 15-74}}$.

[37] Quarterly data provided by our colleagues from the Financial Stability Department point towards no significant difference in the equity to assets ratio between companies with most of the loans in either domestic or foreign currency.

Table 2: *Calibrated parameters*

Parameter	Description	Value
μ_{z^+}	SS growth rate of agg. tech.	1.007
μ_z	SS growth rate of neutral tech.	1.007
μ_ψ	SS growth rate of investment tech.	1
$\bar{\pi}$	SS inflation target	1.00625
α	Capital share in the production	0.55
β	Discount factor	0.9963
$\tau^{d,DC}, \tau^{d,FC}$	Bond/deposit tax rate	0
τ^k	Capital tax rate(%)	0
τ^c	Consumption tax rate(%)	18.05
τ^w	Labour tax rate(%)	18.96
τ_y	Income tax rate(%)	16
ω_c	Import share in cons. goods	0.232
ω_i	Import share in inv. goods	0.465
ω_x	Import share in exp. goods	0.281
ω_o	Oil share in gross output	0.02
ω_q	Trade in EUR share in total trade	0.726
ω_{adm}	Adm. prices goods in CPI basket	0.18
χ_{adm}	Indexation factor adm. prices	0.8
$\tilde{\phi}_{nfa}$	Elasticity of country risk to NFA	0.01
λ_j	Price markups for $j \in \{d, mx, mc, mi, moil\}$	1.2
λ_j	Price markups for $j \in \{x, c\}$	1.05
ϑ_w	Wage indexation to real growth trend	1
$F(\bar{\omega}_{DC})$	SS bankruptcy rate DC entrepreneurs	0.0163
$F(\bar{\omega}_{FC})$	SS bankruptcy rate FC entrepreneurs	0.0177
$\frac{W_e^j}{P^{VA}VA}$	Transfers to $j \in \{DC, FC\}$ entrepreneurs	0.05
L	Steady state fraction of employment	1-0.067
N	Nr. of agency cohorts	4
φ	Curvature of hiring costs	2
ρ	Exogenous survival rate of a match	0.982
σ	Unemployment share in matching tech.	0.5
σ_m	Level parameter in matching function	0.482
ι	Empl. adj. costs on tightness	1
$\eta_{g,\text{real}}$	Param. det. the share of real gov. exp. in GDP	0.13
$\eta_{g,nom}$	Param. det. the share of nominal gov. exp. in GDP	0.19
ρ_g	Persistence parameter real gov. expenditures	0.5
σ_g	St. deviation real gov. expenditures shock	0.3
ftr	Share of net foreign (private) transfers in nom. GDP	0.03
sd	Share of statistical discrepancy in nom. GDP	0.01
Δinv	Share of change in inventories in GFCF	-0.014
$\rho^{\Delta inv}$	Persistence parameter for share of change in inventories	0.5
$\sigma_{\Delta inv}$	St. deviation share of change in inventories shock	0.3

Table 3: *Matched moments and corresponding parameters*

Parameter	Description	Post. mean:	Moment	Moment value
$\tilde{\varphi}$	REER	0.357	$\frac{S^{ef}P^{x}X}{P^{GDP}GDP}$	35.7%
A_L	Scaling of disutility of work	184715	$L\varsigma$	22.7%
δ	Depreciation rate of capital	0.049	$\frac{P^{i}I}{P^{GDP}GDP}$	25%
γ^{DC}	Entrepreneurial survival rate	0.932	$\frac{N^{DC}}{P_t P_{k'} \bar{K}^{DC}}$	0.4
γ^{FC}	Entrepreneurial survival rate	0.892	$\frac{N^{FC}}{P_t P_{k'} \bar{K}^{FC}}$	0.4
ω_k	Share of DC type entrepreneurs	0.407	$\frac{(1-\omega_k)S^{RON/EUR}L^{FC}}{\omega_k L^{DC}}$	84.6%
$p^{oil,USD}$	Price of oil in USD terms	2.990	$\frac{P^{oil}Oil^{m}}{P^{GDP}GDP}$	2%

4.2.2 Excess growth rates parameters

As explained in section 3 before, the observed series display specific growth rates, inconsistent with a balanced growth approach. In dealing with this issue, we follow Argov et al. (2012) approach for model-consistent filtering, removing, when estimating the model, the excess trends of selected variables with respect to the model-implied common trend. Table 4 presents the calibrated parameters that reflect the steady state values for the excess trends. When calibrating these parameters, the average historical values over the analyzed period are taken into account. As mentioned before, for inflation rates, other than inflation target, excess trends over the model implied ones are specified as the *sum of inflation target excess trend and a specific excess trend, with the latter explaining the difference between data mean of a certain variable and sample mean of inflation rate target.* The only exception is for administered prices, for which the steady state value for the excess trend is recovered using those of headline and CORE1 inflation rates. For volumes other than GDP, steady state values for excess trends are specified as the difference between the average historical mean growth rates and that of GDP (μ_{z+}). The exception is represented by government consumption, for which the excess trend is computed as a residual conditional on the weighted sum of excess trends of GDP components (over GDP) being zero.

4.3 Prior distributions

In general, the priors are relatively tight given the small data sample we are working with, and for those of them for which empirical evidence is lacking the values are usually borrowed from other estimated models. Structural parameters' prior distributions are presented in table 5.

For exported, imports for consumption, imports for investment and final consumption goods, we set the priors for price stickiness parameters to 0.667, implying price durations of

Table 4: *Calibrated excess growth rates*

Parameter	Description	Value (%)	
$\mu^{\bar{\pi}^c} - \bar{\pi}$	Excess growth rate inflation target	3.6-2.5	1.1
$\mu^{\pi^{GDP}} - \mu^{\bar{\pi}^c}$	Excess growth rate GDP deflator	6.9-3.6	3.3
$\mu^{\pi^c} - \mu^{\bar{\pi}^c}$	Excess growth rate CPI inflation	4.8-3.6	1.2
$\mu^{\pi^{core1}} - \mu^{\bar{\pi}^{core1}}$	Excess growth rate CORE1 inflation	4.4-3.6	0.8
$\frac{\mu^{\pi^c} - \mu^{\bar{\pi}^c} - (1-\omega_{adm})\left(\mu^{\pi^{core1}} - \mu^{\bar{\pi}^{core1}}\right)}{\omega_{adm}}$	Excess growth rate adm. prices inflation	6.6-3.6	3
$\mu^{\pi^i} - \mu^{\bar{\pi}^c} - 400 \log \mu_{\psi}$	Excess growth rate investment inflation	6.9-3.6-0	3.3
$\mu^{\pi^x} - \mu^{\bar{\pi}^c}$	Excess growth rate exports inflation	5.2-3.6	1.6
$\mu^{\pi^m} - \mu^{\bar{\pi}^c}$	Excess growth rate imports inflation	2.8-3.6	-0.8
$\mu^c - 100 \log \mu_{z^+}$	Excess growth rate private cons. volume	0.9-0.7	0.2
$\mu^i - 100 \log(\mu_{z^+} \mu_{\psi})$	Excess growth rate investment volume	0.5-0.7-0	-0.2
$-\frac{s^c\mu^c + s^i\mu^i + s^x\mu^x - s^m\mu^m}{s^g}$ $\frac{+100 \log \mu_{z^+} * \left(s^c + s^i + s^x - s^m\right)}{s^g}$	Excess growth rate gov. cons. volume	0.1-0.7	-0.6
$\mu^x - 100 \log \mu_{z^+}$	Excess growth rate exports volume	1.7-0.7	1
$\mu^m - 100 \log \mu_{z^+}$	Excess growth rate imports volume	1.6-0.7	0.9

three quarters. These values are slightly above the ones resulting from the micro-evidence presented in Copaciu et al. (2010) and Iordache and Pandioniu (2015) for Romanian firms where the average duration is slightly lower. While for administered prices we follow an empirical regularity and set the prior for price stickiness, ξ_{adm}, to 0.75, consistent with an average price duration of one year, for intermediate domestic, imported for exports and oil imported goods the priors are set at 0.5, implying price durations of two quarters. The prior uncertainty is assumed to be relatively low, namely 0.075, with the exception of domestic intermediate goods for which is set at 0.05[38]. The priors for the indexation parameters to past inflation are centered to 0.5, with an associated standard deviation of 0.1. For the working capital share parameters, which similar to Christiano et al. (2011), are assumed to be equal across sectors, a prior of 0.2 is chosen, with an associated standard deviation of 0.075. For the administered price rule parameters, we follow de Castro et al. (2011) and set ν^1_{adm} and ν^2_{adm}, the exchange rate and marginal costs coefficients in the administered price rule, to 0.05 and 0.2 respectively, with standard deviations of 0.03 and 0.05.

We follow Christiano et al. (2011), and set the prior for the inverse Frisch elasticity to 7.5, with a standard deviation of 0.5. The resulting prior value for the Frisch labor supply elasticity, centered around 0.13, is in line with the range of estimates usually obtained in

[38]A lower and tighter prior on ξ_d was necessary to generate the convergence between posterior mode and posterior mean, as well as a positive response of investment to a temporary technological shock, given the low value of estimated investment adjustment cost parameter (needed to better match the relatively volatile investment series).

micro studies[39]. The prior for the habit persistence parameter is centered at 0.65, a common value used in the literature. The prior for the investment adjustment costs is set to the value used previously by Christiano et al. (2005) and Smets and Wouters (2007), namely 4 with a standard deviation of 1.5, while the prior for the variable capital utilization parameter is borrowed from Smets and Wouters (2007), centered at 0.5, with an associated standard deviation of 0.15.

The priors for the Taylor rule parameters are centered to values close to those in Christiano et al. (2011), while the associated standard deviations are smaller. Thus, the prior for the persistence parameter in the reaction function is centered at 0.8 (standard deviation of 0.05), the parameter governing the response of interest rate to inflation to 1.7 (standard deviation of 0.1), while we impose a very tight prior on the parameter controlling for the reaction to the deviation of output from its steady state value (centered to 0.15, with an associated standard deviation of 0.01).

Following a wide literature, the priors for the elasticities of substitution are set to 1.5, with associated standard deviations of 0.1, with two exceptions: the elasticity of substitution between the two categories of capital services, η_k, for which the prior value is centered at 2.5 (standard deviation of 0.5), and the elasticity of substitution between imported oil and gross value added, η_o, with the prior set at 0.1 (standard deviation of 0.05).

The prior for the parameters reflecting the monitoring costs, μ_j, are set to 0.4 and 0.3 for the DC and FC entrepreneurs, with standard deviations of 0.075 each.

In setting the prior for the relative flow value of utility of an unemployed person relative to a worker, *bshare*, the evidence regarding the replacement ratio after tax for Romania is, at a first look, rather mixed: while van Vliet and Caminada (2012) report replacement rates for the 2003-2009 period of around 60%, OECD data[40] for 2008-2010 points towards a significantly lower average value (i.e. 32%), even when compared over the two years common period covered. The differences can be traced in the methodologies employed, the main ones, in order of their importance, being: first, while the former study looks into the initial phase of unemployment assuming a 6 month unemployment spell, the OECD data is computed for persons in the 60th month of unemployment benefits; second, while OECD data looks at two earning levels and three family situations, van Vliet and Caminada (2012) cover two family situations and one earning level. Based on all this evidence, and given that we assume here an average duration of unemployment of around 11 months, we set the prior for the relative flow value of utility of an unemployed person relative to a worker to 0.5, with a relatively tight standard deviation of 0.05. The prior for the endogenous separation rate, $F(\%)$, is set at 0.2%, representing 10% of the total separation rate. As for the share of hiring costs in GDP, $hshare(\%)$, we follow Christiano et al. (2011) and set the prior at 0.1%, with an associated standard deviation of 0.05.

Structural shocks' auto-regressive coefficients and standard deviations are presented in table 6. The prior values for the persistence parameters in the markup shocks and foreign transfers laws of motion are set at 0.5, with standard deviations of 0.1. The prior for

[39]Pencavel (1987) surveys the early estimates on Frisch elasticity for U.S. and reports values ranging between 0 and 0.45, with the mean value being around 0.2. More recent estimates are usually larger: correcting for small sample bias, Lee (2001) finds values for men around 0.5, a similar value being reported by Ziliak and Kniesner (2005).

[40]Available at: http://www.oecd.org/dataoecd/60/8/49971171.xlsx.

the persistence parameter of the inflation target is set at 0.84, the value resulted from an univariate AR(1) regression, with a standard deviation of 0.05. We set a very tight prior for the AR(1) persistence parameter of the growth rate of neutral technology, that is 0.95 with a standard deviation of 0.01. The priors for the persistence parameters for the remaining shocks in the core domestic model are set at 0.75 (standard deviation of 0.075).

We favor little persistence in the excess trends equations, by setting the prior values for the persistence parameters to 0.15 (standard deviation of 0.05), with the exception of the inflation target excess trend equation for which an even lower value is selected, namely 0.1 (standard deviation of 0.025). These are presented in table 15 in Appendix.

4.4 Shocks and measurement errors

Out of the potential shocks from the model, we shut down in estimation those with a very limited effect when preliminary estimations were performed or those resulting as irrelevant given the modeling choices. Similar to Christiano et al. (2011), tax rates are assumed to be constant. Furthermore, we exclude in estimation: the idiosyncratic entrepreneur risk shocks (σ_t^{DC} and σ_t^{FC}) as they had an extremely limited effect when preliminary estimations were performed[41]; the shock affecting the standard deviation of workers' productivity ($\sigma_{a,t}$); the shock to bargaining power (η_t) and the shock to matching technology ($\sigma_{m,t}$), since we do not observe vacancies. Similarly, consistent with the calibration of $\mu_{\psi,t}$ (see subsection 4.2), the investment specific technology shock was shut down, as deemed irrelevant. Other shut down/calibrated shocks were $\varepsilon_{g,t}$, $\varepsilon_{pg,t}$, $\varepsilon_{sd,t}$, $\varepsilon_{\Delta inv,t}$ corresponding to variables no included in the observed dataset: government consumption (volume and prices), statistical discrepancy and change in inventories. This gives us a total of 18 structural shocks in estimation of the domestic core model. These are assumed to follow AR(1) processes, with the exception of the monetary policy shock ($\varepsilon_{R,t}$), the foreign transfers shock ($\varepsilon_{ftr,t}$) and the inflation target innovation ($\varepsilon_{\bar{\pi},t}$).

- Stationary neutral technology ϵ_t
- Permanent neutral technology $\mu_{z,t}$
- Marginal efficiency of investment Υ_t
- Consumption preference ζ_t^c
- Labor disutility ζ_t^h
- Risk premium $\tilde{\phi}_t$
- Monetary policy $\varepsilon_{R,t}$
- Entrepreneurial wealth DC γ_t^{DC}
- Entrepreneurial wealth FC γ_t^{FC}
- Markup, domestic intermediate τ_t^d
- Markup, exports τ_t^x
- Markup, imports for consumption τ_t^{mc}
- Markup, imports for investment τ_t^{mi}
- Markup, imports for exports τ_t^{mx}
- Markup, imports of oil τ_t^{moil}
- Administered prices Z_t^{adm}
- Foreign transfers $\varepsilon_{ftr,t}$
- Inflation target $\varepsilon_{\bar{\pi},t}$

Additionally, the foreign core model includes 8 structural shocks, assumed as i.i.d. processes :

[41] There is a problem in identifying the effects of these shocks as they have rather similar effects with the entrepreneurial wealth ones for each category of entrepreneurs which might explain why their effects are crowded out when estimation is performed. Moreover, we do not observe net worth, either as an aggregate measure, nor for each type of entrepreneurs.

• Aggregate demand Euro area	$\varepsilon_{y^{EUR},t}$	• Monetary policy Euro area	$\varepsilon_{R^{EUR},t}$
• Aggregate demand US	$\varepsilon_{y^{US},t}$	• Monetary policy US	$\varepsilon_{R^{US},t}$
• Philips curve Euro area	$\varepsilon_{\pi^{EUR},t}$	• USD/EUR UIP	$\varepsilon_{uip^*,t}$
• Philips curve US	$\varepsilon_{\pi^{US},t}$	• USD real oil price	$\varepsilon_{oilusd,t}$

Furthermore, we follow the standard practice in Bayesian estimation of DSGE models and include measurement errors/excess trends when specifying the equations linking actual data to the model endogenous variables. There are some technical reasons for using measurement errors: on one hand, measurement errors may account for model misspecification, if the restrictions implied by the model equations are at odds with the data (Del Negro and Schorfheide (2009)). On the other, measurement errors can solve the problem of stochastic singularity, when the number of observed variables exceeds the number of structural shocks. Nevertheless, the main reason for using measurement errors is the considerable noise the macroeconomic time series are measured with.

The uncertainty related to the observed variables becomes obvious when analyzing the revisions magnitudes operated by the Romanian National Institute of Statistics (NIS) to the quarterly seasonally adjusted National Accounts data. We show three vintages (October 2014, October 2013 and October 2012) of GDP and components data in figures 6 (real quantities) and 7 (deflators). The sizable revisions, particularly for the crisis period, suggest little reliability of the published data and the need for measurement errors when modeling the national accounts data.

Nalban (2015) analyzes the pattern of past revisions and tries to quantify the "true" GDP data (net of potential revisions) and its associated uncertainty. The findings show that revisions' pattern of Romanian data does not always comply with model's hypotheses, as sometimes more distant observations are also revised, not only the recent ones (as it is visible also in figures 6 and 7). Furthermore, the operated revisions present noise effects, meaning there is significant evidence in favor of random measurement errors contained in official releases. Although there was not signaled the existence of systematic errors (i. e. on average the revisions are null), relatively to the United Kingdom and the US data, the estimated variance of the measurement error is about three times larger, suggesting an increased uncertainty associated to the Romanian times series.

For both excess trends innovations and white noise measurement errors, the priors for their standard deviations are specified as inverse gamma distributions with means equal to 10% of the variance of the corresponding observed series and 100 degrees of freedom.

Figure 6: *Data revisions across three vintages - 100*qoq growth rates, percent - volumes*

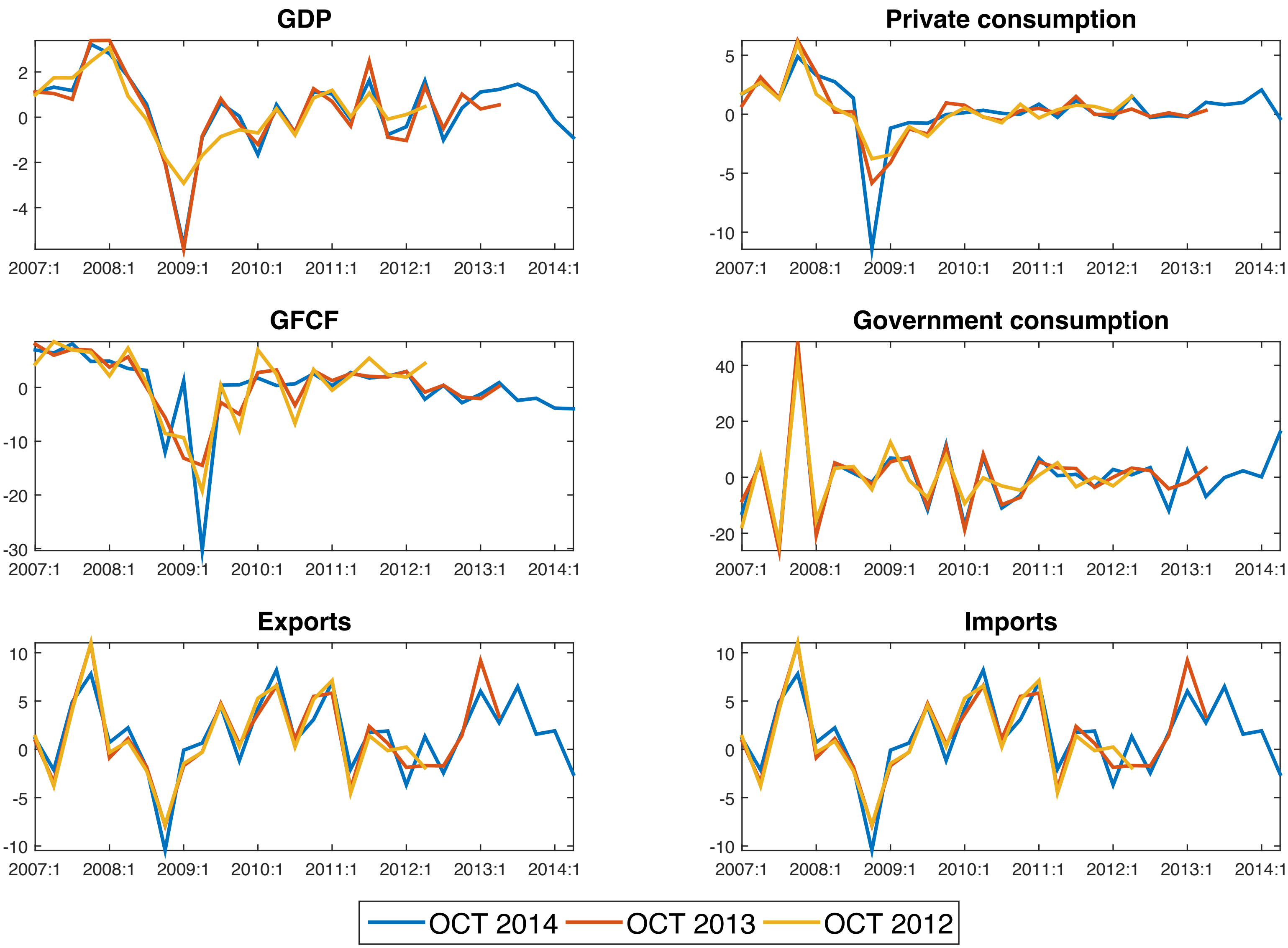
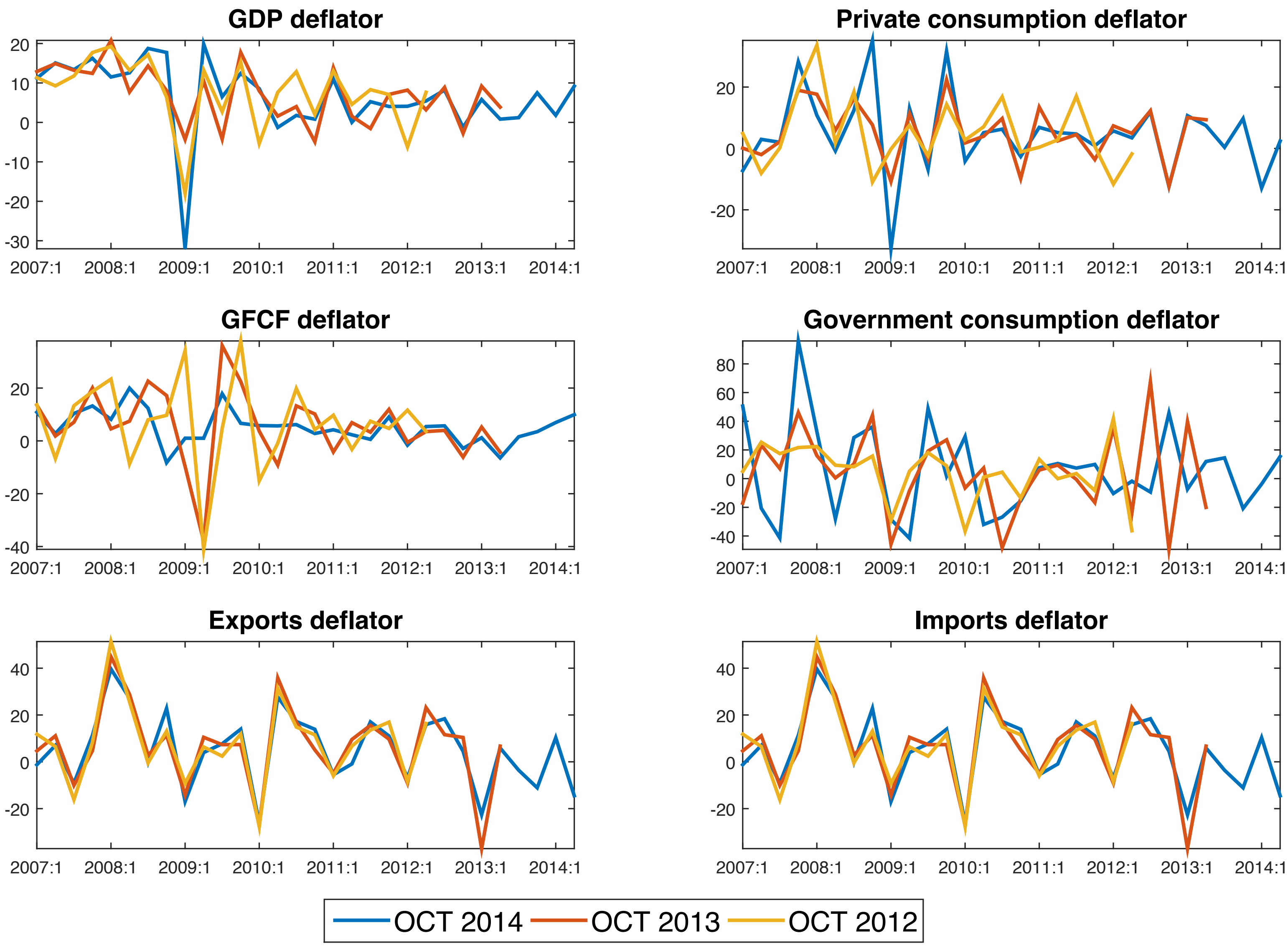


Figure 7: *Data revisions across three vintages - 400*qoq growth rates, percent - deflators*



4.5 Estimation results

4.5.1 Posterior parameter values

The posterior parameters and standard deviations values for the full model are reported in tables 5-6 below. In general, the results point towards a relatively high degree of uncertainty surrounding the posterior mean values, as measured by the 10th and 90th percentile. This is related to the short data sample available (specific to emerging economies), and to the sizable parameter space covered.

The highest degree of price stickiness is displayed by prices of imported consumption, imported investment and administered goods. The remaining Calvo parameters point towards a high degree of price flexibility. The latter result validates the survey based evidence regarding price setting behavior of Romanian firms as provided in Copaciu et al. (2010) and Iordache and Pandioniu (2015). Moreover, this was an expected result given the highly volatile observed inflation series. Relative to estimates for other economies, they are lower when compared with those usually obtained for developed economies, but in line with the results for other emerging economies: Elekdag and Alp (2011) report median values of ξ between 0.3-0.56 for Turkey, Ajevskis and Vitola (2011) report a value of 0.53 for Latvia, while Grabek et al. (2011) find slightly higher values, between 0.53-0.8 for Poland. There are also a number of studies for developed countries that find similar values for the degree of price stickiness: for Israel, Argov et al. (2012) indicate the range 0.43-0.6, Pedersen and Ravn (2013) report a value of 0.48 for Denmark, Elekdag et al. (2006) find a median value of 0.51 for Korea, while for Taiwan, Teo (2006) estimates values between 0.48 and 0.7.

The mean values for the parameters governing the degree of indexation of prices to lagged inflation are (slightly) below the 0.5 prior value, although it should be mentioned that for most of these parameters, data is rather uninformative. The latter situation is met also in the case of the estimated values for the administered price rule parameters, most of the elasticities of substitution and the working capital share.

The estimated mean value for the parameter governing the habit persistence in consumption, b, is 0.38, relatively low when compared with estimates for other economies, but rather justified given the relatively high volatility of observed private consumption series that we are trying to match with the endogenous priors procedure[42]. The estimated curvature of the labor supply, σ_L, is close to its prior value, implying values for the Frisch elasticity of labor supply around 0.13. The latter value is at the lower end of the estimates found in the micro data based studies and in line with the estimated values found in DSGE models that include employment frictions in their structure[43].

The mean estimated value of the investment adjustment cost parameter (S'') is very low (i.e. 0.25), while the mean estimated values for the capacity utilization parameters, $\sigma_{a,DC}$ and $\sigma_{a,FC}$, are 0.60 and 0.37 respectively. According to our intuition, these values can be reconciled with the need of the model to match both an extremely volatile investment series and a relatively less volatile output one.

[42]When estimating the same model without the endogenous priors procedure, the mean value of the habit persistence parameter is 0.64, very close to the 0.65 prior value.

[43]Christiano et al. (2011) find a value around 0.13 for Sweden while Gertler et al. (2008) and Galí et al. (2011) estimate a value around 0.25 for US.

Regarding the estimated Taylor rule parameters, the interest rate smoothing parameter is estimated at 0.79, in line with estimates from other studies. The response to the deviation of inflation from the target has a mean value of 2.11, a similar estimate with the one of Elekdag et al. (2006) for Korea. A higher estimate (i.e. 2.66) is obtained by Argov et al. (2012) for Israel, while Elekdag and Alp (2011) presents a lower value for Turkey. As for the response of policy rate to the deviation of output from its steady state value, it is estimated at 0.12, close to the (tight) prior we assumed.

The mean estimated values for the monitoring costs parameters, μ_{DC} and μ_{FC}, are 0.37 and 0.58. The corresponding steady-state values for the spreads at the posterior mean are 2.8 and 4.5 percentage points respectively. While the latter value is close to its data counterpart (i.e. the average value of the spread for new loans to non-financial corporations in EUR is 4 percentage points over the analyzed period), the model implied spread for domestic currency loans is lower than its empirical value (i.e. 5 percentage points). Thus, while starting from data consistent prior values according to which spreads are higher for domestic currency loans relative to foreign currency ones, the estimation of the monitoring costs parameters generates higher values for the latter category. However, the results are in line with the volatility of the change in spreads. Namely, in the data, the volatility of the (change in) spreads for domestic currency loans is substantially higher than the similar measure for the foreign currency ones, as shown in table 7. When employing the endogenous prior procedure, the model needs higher monitoring costs for foreign currency loans in order to generate a relatively less volatile series, as in the data.

If one ignores the above mentioned relations between the (volatility of the) spreads and monitoring, it might be argued that the estimated values of the monitoring costs are relatively high when compared with those obtained in other studies. However, recovery rates[44] data for Romania, as reported by the World Bank as part of its Doing Business project[45] are relatively low (i.e. 30.7 cents on the dollar). If one uses them as proxy for $(1 - \mu)$, the corresponding value for μ is 0.693, even higher than our estimates. The recovery rates are much smaller (and implicitly μ lower) for US (80.4 cents on the dollar) or Sweden (76.1 cents on the dollar), with a value of 40.2 cents on the dollar for Hungary.

The estimated recruitment share, $hshare(\%)$, represent 0.13% of GDP, while data is rather uninformative with respect to the relative flow value of utility of an unemployed person relative to a worker ($bshare$), whose mean estimated value is close to its prior, namely 0.49. The estimated value of the endogenous separation rate, $F(\%)$, implies that around 10% of job separations are endogenous.

The estimates for the standard deviations of shocks and the corresponding auto-regressive parameters are presented in table 6, while the similar estimates for the excess trends are presented in table 15 from the Appendix.

As mentioned before, we chose to match seven observed ratios and consequently recalibrate the corresponding parameters for each draw, with the posterior mean of the latter presented in table 3.

The mean value for the depreciation rate is 4.9% per quarter, a relatively high value

[44] Recovery rates "calculates how many cents on the dollar secured creditors recover from an insolvent firm at the end of insolvency proceedings." (World Bank)

[45] The project measures and compares regulations relevant to the life cycle of a small to medium-sized domestic business in 189 economies. The data presented here is part of the June 2014 release.

when compared with the calibrated values in other studies, usually centered at 2.5%. The explanation comes from the relatively high spreads that are present in the model, which impact negatively on the size of the capital stock[46], while at the same time the ratio of investment to GDP we are matching is relatively high.

The calibrated mean values of the entrepreneurial survival rates are relatively low, also reflecting the high empirical bankruptcy rates we impose in the model.

The mean value for the share of entrepreneurs borrowing in domestic currency, ω_k, is 0.4 (i.e. 40%), less than 0.5. This latter fact might come as a surprise given that the prior values indicated higher spreads for those borrowing in domestic currency and implicitly a lower capital per entrepreneur relative to those getting funds in foreign currency. Furthermore, given that we are matching an average ratio of domestic to foreign currency credit to non-financial corporations of about 1.2, a higher than 0.5 value for ω_k was expected (i.e. more entrepreneurs borrowing, each relatively less, in domestic currency). However, for reasons described before, the estimation of the monitoring costs parameters generates higher posterior values for the spreads for foreign currency loans relative to domestic currency ones. Implicitly, the capital of one entrepreneur borrowing in domestic currency is higher relative to the one of an entrepreneur borrowing in foreign currency. Therefore, in order to accommodate, for all entrepreneurs, an average ratio of domestic to foreign currency credit to non-financial corporations of about 1.2, the share of domestic entrepreneurs should be smaller than 0.5.

[46]At the posterior mean steady state, the capital to GDP ratio, when expressed in nominal terms, is low (i.e. 1.2), with the equivalent measure in real terms being 2.4.

Table 5: *Estimated structural parameters*

Based on single Metropolis chain with 400,000 draws, after a burn in period of 200,000 draws.								
Parameter	Description		Prior			Posterior		
		Distr.	Mean	s.d.	Mean	s.d.	10%	90%
ξ_d	Calvo, domestic	β	0.5	0.05	0.464	0.054	0.374	0.550
ξ_x	Calvo, exports	β	0.667	0.075	0.336	0.043	0.265	0.406
ξ_{mc}	Calvo, imp. cons.	β	0.667	0.075	0.604	0.093	0.450	0.754
ξ_{mi}	Calvo, imp. inv.	β	0.667	0.075	0.730	0.060	0.635	0.829
ξ_{mx}	Calvo, imp. exp.	β	0.5	0.075	0.372	0.058	0.275	0.469
ξ_{moil}	Calvo, imp. oil	β	0.5	0.075	0.484	0.075	0.361	0.608
ξ_c	Calvo, core1 cons.	β	0.667	0.075	0.465	0.053	0.380	0.552
ξ_{adm}	Calvo, adm. cons.	β	0.75	0.075	0.740	0.042	0.670	0.807
κ_d	Indexation, domestic	β	0.5	0.1	0.363	0.091	0.215	0.513
κ_x	Indexation, exports	β	0.5	0.1	0.415	0.094	0.263	0.571
κ_{mc}	Indexation, imp. cons.	β	0.5	0.1	0.466	0.102	0.296	0.623
κ_{mi}	Indexation, imp. inv.	β	0.5	0.1	0.494	0.100	0.329	0.656
κ_{mx}	Indexation, imp. exp.	β	0.5	0.1	0.425	0.095	0.273	0.585
κ_{moil}	Indexation, imp. oil	β	0.5	0.1	0.498	0.101	0.334	0.668
κ_c	Indexation, core1 cons.	β	0.5	0.1	0.242	0.070	0.127	0.352
κ_w	Indexation wages	β	0.5	0.1	0.412	0.093	0.257	0.565
ν^j	Working capital share	β	0.2	0.075	0.192	0.074	0.074	0.310
σ_L	Inverse Frisch elasticity	Γ	7.5	1.5	7.822	1.276	5.692	9.836
b	Habit share in cons.	β	0.65	0.1	0.380	0.063	0.275	0.483
S''	Inv. adj. costs	N	4	1.5	0.251	0.048	0.173	0.328
$\sigma_{a,DC}$	Variable capital util. DC	Γ	0.5	0.15	0.598	0.139	0.375	0.822
$\sigma_{a,FC}$	Variable capital util. FC	Γ	0.5	0.15	0.371	0.088	0.229	0.508
ρ_R	Taylor, lagged int. rate	β	0.8	0.05	0.787	0.019	0.757	0.819
r_π	Taylor, inflation	N	1.7	0.1	2.112	0.080	1.982	2.246
r_y	Taylor, output	N	0.15	0.01	0.118	0.01	0.102	0.135
η_x	E.o.s., exports	Γ	1.5	0.1	1.399	0.087	1.253	1.538
η_c	E.o.s., consumption	Γ	1.5	0.1	1.312	0.082	1.179	1.446
η_i	E.o.s., investment	Γ	1.5	0.1	1.517	0.093	1.365	1.672
η_f	E.o.s., foreign	Γ	1.5	0.1	1.729	0.087	1.584	1.869
η_k	E.o.s., capital services	Γ	2.5	0.5	2.595	0.498	1.746	3.359
η_o	E.o.s., oil	Γ	0.1	0.05	0.095	0.051	0.019	0.169
μ_{DC}	Monitoring cost DC	β	0.4	0.075	0.371	0.039	0.307	0.435
μ_{FC}	Monitoring cost FC	β	0.3	0.075	0.581	0.059	0.484	0.676
$hshare(\%)$	Share of hiring costs to GDP	Γ	0.1	0.05	0.129	0.022	0.093	0.164
$bshare$	Utility flow unemployed	β	0.5	0.05	0.493	0.049	0.413	0.575
$F(\%)$	End.separation rate	β	0.2	0.05	0.147	0.033	0.092	0.201
v^1_{adm}	Adm. prices, RER	β	0.05	0.03	0.057	0.033	0.008	0.106
v^2_{adm}	Adm. prices, RMC	β	0.2	0.05	0.021	0.049	0.122	0.283

Table 6: *Estimated auto-regressive coeff. and standard deviations - structural shocks*

Based on single Metropolis chain with 400,000 draws, after a burn in period of 200,000 draws.

Parameter	Description	Prior			Posterior			
		Distr.	Mean	s.d.	Mean	s.d.	10%	90%
ρ_{μ_z}	Pers., unit-root tech.	β	0.95	0.01	0.906	0.0124	0.886	0.926
ρ_{ϵ}	Pers., stationary tech.	β	0.75	0.075	0.648	0.069	0.538	0.761
ρ_{Υ}	Pers., MEI	β	0.75	0.075	0.638	0.068	0.529	0.752
ρ_{ζ^c}	Pers., cons. prefs.	β	0.75	0.075	0.628	0.053	0.545	0.715
ρ_{ζ^h}	Pers., labor prefs.	β	0.75	0.075	0.752	0.065	0.649	0.860
$\rho_{\tilde{\phi}}$	Pers., risk premium	β	0.75	0.075	0.721	0.053	0.635	0.808
$\rho_{\gamma,DC}$	Pers., entrepren. wealth DC	β	0.75	0.075	0.715	0.057	0.624	0.810
$\rho_{\gamma,FC}$	Pers., entrepren. wealth FC	β	0.75	0.075	0.726	0.070	0.618	0.845
ρ_{τ^x}	Pers., exp. markup	β	0.5	0.1	0.391	0.093	0.241	0.545
$\rho_{\tau^{mc}}$	Pers., imp. cons. markup	β	0.5	0.1	0.438	0.099	0.274	0.596
$\rho_{\tau^{mi}}$	Pers., imp. inv. markup	β	0.5	0.1	0.458	0.096	0.298	0.616
$\rho_{\tau^{mx}}$	Pers., imp. exp. markup	β	0.5	0.1	0.393	0.083	0.258	0.529
ρ_{τ^d}	Pers.,intermediate domestic	β	0.5	0.1	0.358	0.100	0.198	0.512
$\rho_{\tau^{moil}}$	Pers., imp. oil markup	β	0.5	0.1	0.531	0.116	0.333	0.716
ρ_{adm}	Pers., adm. prices markup	β	0.5	0.1	0.295	0.066	0.185	0.401
ρ_{π}	Pers., inflation target	β	0.84	0.05	0.910	0.025	0.869	0.950
ρ_{ft}	Pers., foreign transf.	β	0.5	0.1	0.479	0.092	0.332	0.635
Parameter	Description	Prior			Posterior			
		Distr.	Mean	s.d.	Mean	s.d.	10%	90%
$100\sigma_{\mu_z}$	Unit root tech.	Inv-Γ	0.3	2	0.100	0.019	0.069	0.131
$100\sigma_{\epsilon}$	Stationary tech.	Inv-Γ	0.65	2	0.731	0.099	0.568	0.891
$10\sigma_{\Upsilon}$	MEI	Inv-Γ	0.3	2	0.100	0.014	0.078	0.122
$10\sigma_{\zeta^c}$	Consumption pref.	Inv-Γ	0.3	2	0.336	0.037	0.276	0.396
$10\sigma_{\zeta^h}$	Labor pref.	Inv-Γ	0.3	2	0.639	0.113	0.454	0.818
$100\sigma_{\tilde{\phi}}$	Country risk premium	Inv-Γ	0.3	2	0.409	0.067	0.297	0.515
$100\sigma_{\epsilon_R}$	Monetary policy	Inv-Γ	0.3	2	0.273	0.024	0.234	0.313
$1000\sigma_{\bar{\pi}^c}$	Inflation target	Inv-Γ	0.5	2	1.429	0.220	1.054	1.775
$10\sigma_{\tau^d}$	Markup, domestic	Inv-Γ	0.65	2	0.383	0.077	0.261	0.510
$10\sigma_{\tau^x}$	Markup, exports	Inv-Γ	0.65	2	0.360	0.081	0.230	0.488
$10\sigma_{\tau^{mc}}$	Markup, imp. for cons.	Inv-Γ	0.65	2	0.446	0.183	0.175	0.724
$10\sigma_{\tau^{mi}}$	Markup, imp. for invest.	Inv-Γ	0.65	2	0.261	0.079	0.147	0.374
$10\sigma_{\tau^{m,x}}$	Markup, imp. for exp.	Inv-Γ	0.65	2	1.586	0.313	1.072	2.064
$10\sigma_{adm}$	Markup, adm. cons.	Inv-Γ	0.65	2	0.073	0.005	0.065	0.082
$10\sigma_{\tau^{moil}}$	Markup, imp. oil	Inv-Γ	0.65	2	2.572	2.637	0.145	6.697
$100\sigma_{\gamma,DC}$	Entrepreneurial wealth DC	Inv-Γ	0.65	2	1.418	0.176	1.132	1.711
$100\sigma_{\gamma,FC}$	Entrepreneurial wealth FC	Inv-Γ	0.65	2	0.411	0.181	0.157	0.686
$100\sigma_{ft}$	Δ (Foreign transfers/GDP)	Inv-Γ	0.3	2	0.308	0.027	0.265	0.351

4.5.2 Impulse response functions

Conducting impulse response functions (IRFs) exercises is a standard procedure for assessing if the model specification is consistent with economic theory, by tracing the behavior of the variables following the occurrence of shocks (one at a time). At the same time, IRFs serve as a preliminary exercise before using the model for more complex policy simulations.

In this section we analyze the responses to a limited number of shocks, namely monetary policy, stationary neutral technology, intermediate domestic markup, consumption preference, risk premium and entrepreneurial net wealth, while the rest of the IRFs are presented in the appendix. The shocks have a magnitude of one standard deviation (see table 6 for the estimated values) and the variables are in deviations from steady state, with the units being either annualized basis points (ABP), percentage deviation (% dev.) or level deviation (lev. dev.). Shaded areas represent 40 percent (30th and 70th percentiles) and 80 percent (10th and 90th percentiles) highest posterior densities, indicating the uncertainty associated with both parameter values and shock magnitude[47].

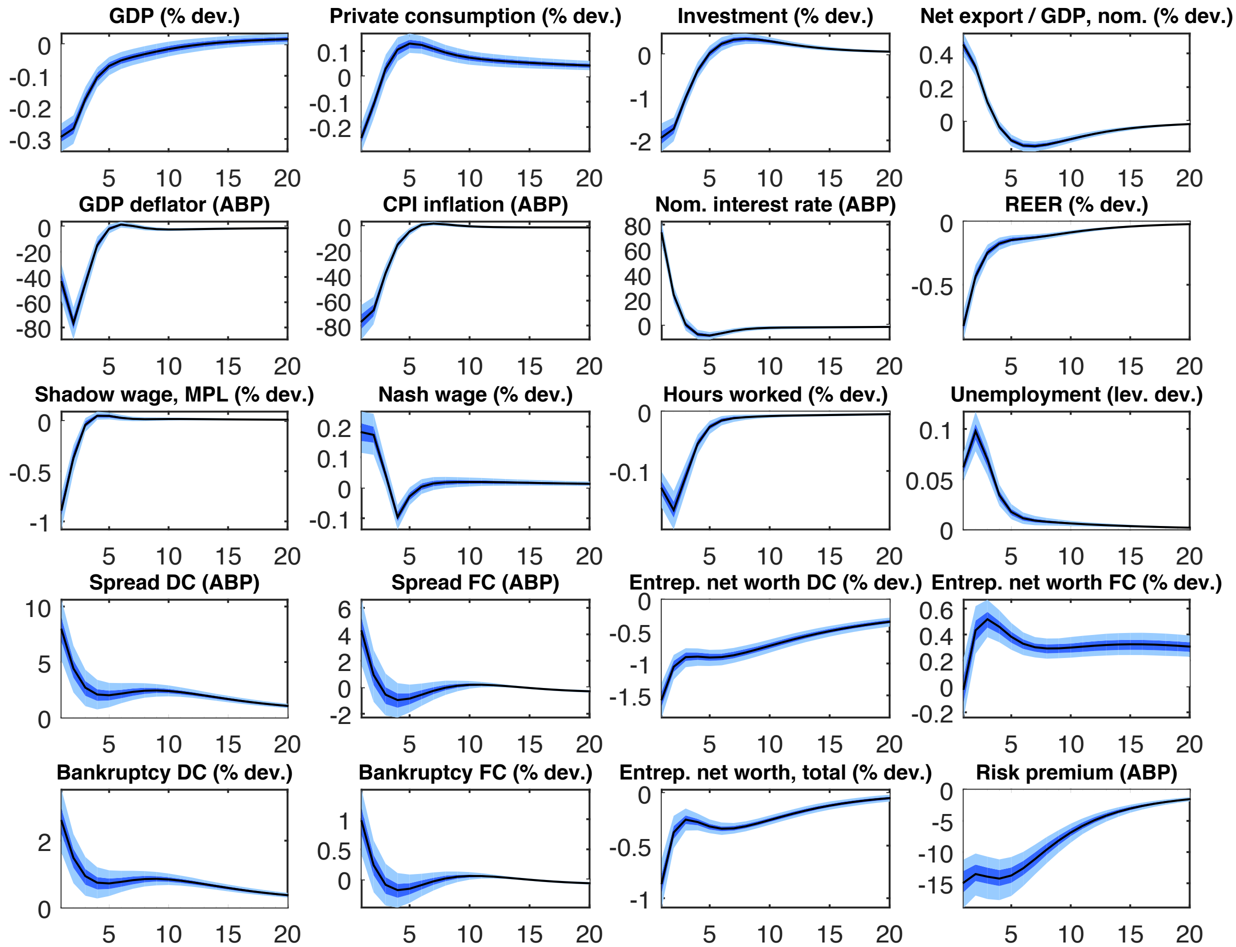
Figure 8 illustrates the IRFs to the **monetary policy shock** ($\varepsilon_{R,t}$), which generates a 75 basis points initial response from the NBR interest rate. As mentioned, this shock is not specified as an AR(1) process, returning to zero after the first period. The interest rate displays some persistence but very limited, returning to steady state after 3 periods, despite the relatively high estimate of the auto-regressive coefficient in the Taylor rule (0.8); the reason for this is the reaction to inflation and output deviations from steady state. CPI inflation falls below steady state in the first period by approximately 75 basis points, with most of the impact dissipating after one year. Behind the inflation dynamics stands a decline in real marginal costs for both domestic and imported consumption goods. The latter are driven by the exchange rate appreciation, while the former by a fall in rental rate on capital and wages.

Regarding the response of real GDP components, a feature common to all simulations is the strong reaction of investment. As mentioned in section 4.5.1, the investment adjustment costs are low in our model, allowing investment to respond substantially. The main factor depressing investment is the increase in the interest rate, which given the existent financial frictions affects the volume of loans denominated in domestic currency. Entrepreneurial net worth is affected by the decline in the price of capital, with an additional influence coming from the debt deflation channel, as disinflation raises the real value of debt. While for entrepreneurs borrowing in foreign currency, the impact of debt deflation channel is outweighed by the appreciation of the exchange rate and the improvement of risk premium (along with net foreign assets position), the effect on entrepreneurs financed through domestic currency loans is stronger, leading to a decline in total net worth, and furthermore an increase in the corresponding spread.

Given the significant imported content of investment (46.5%), total imports and, to a lesser degree, net exports are also driven by the dynamics of investment. Consumption falls as the increase in interest rates provides an incentive for household to save. Consequently, GDP declines, returning to its steady state level after around two years; the impact in the first period is around 0.3 percent. Total hours worked drop, both along the intensive

[47]The standard deviation of a shock is itself a parameter with an posterior probability density, hence the shock associated uncertainty.

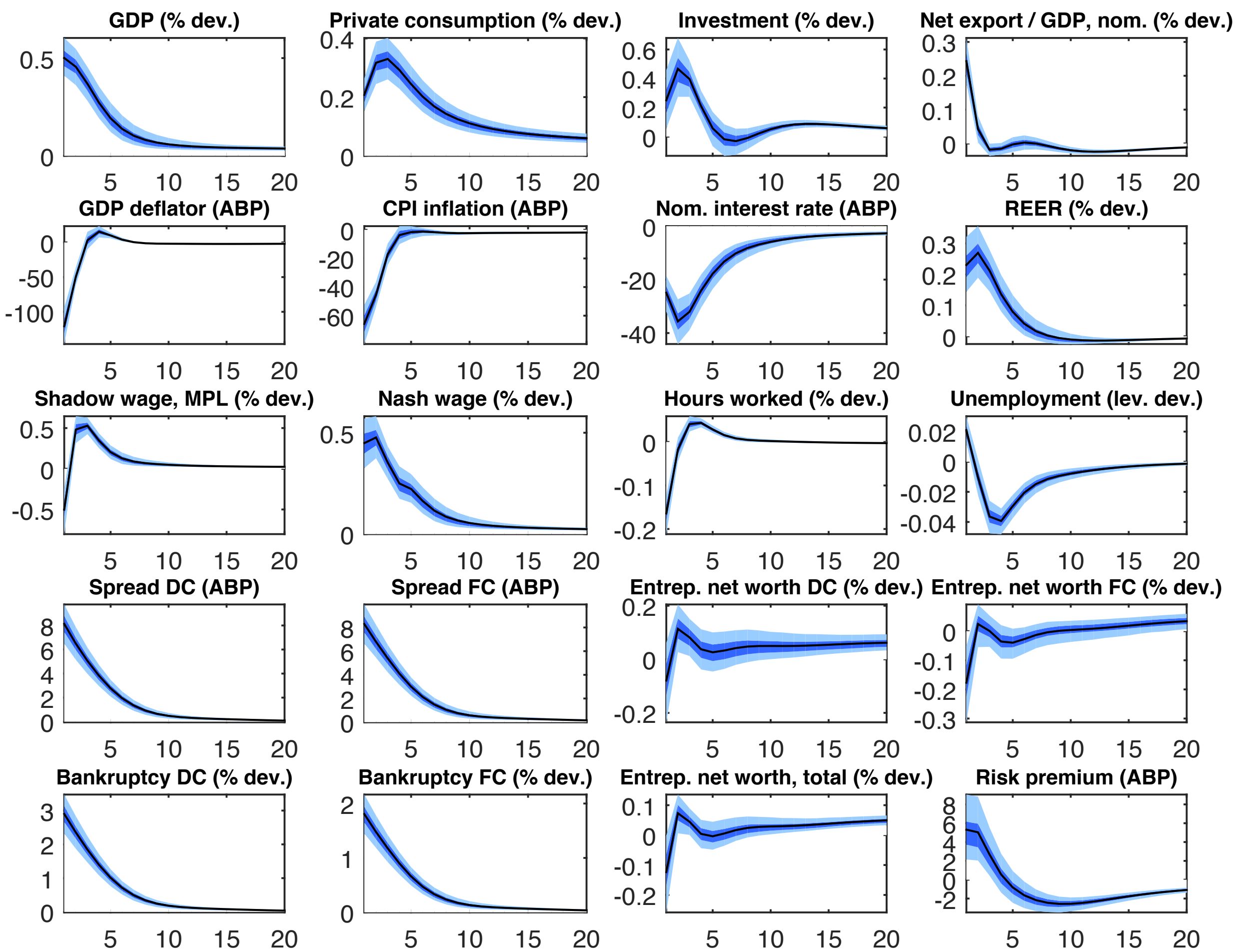
Figure 8: *IRFs to the monetary policy shock*



and extensive margins (i.e. hours per employee and employment), with unemployment temporarily increasing around 0.1 percentage points above equilibrium.

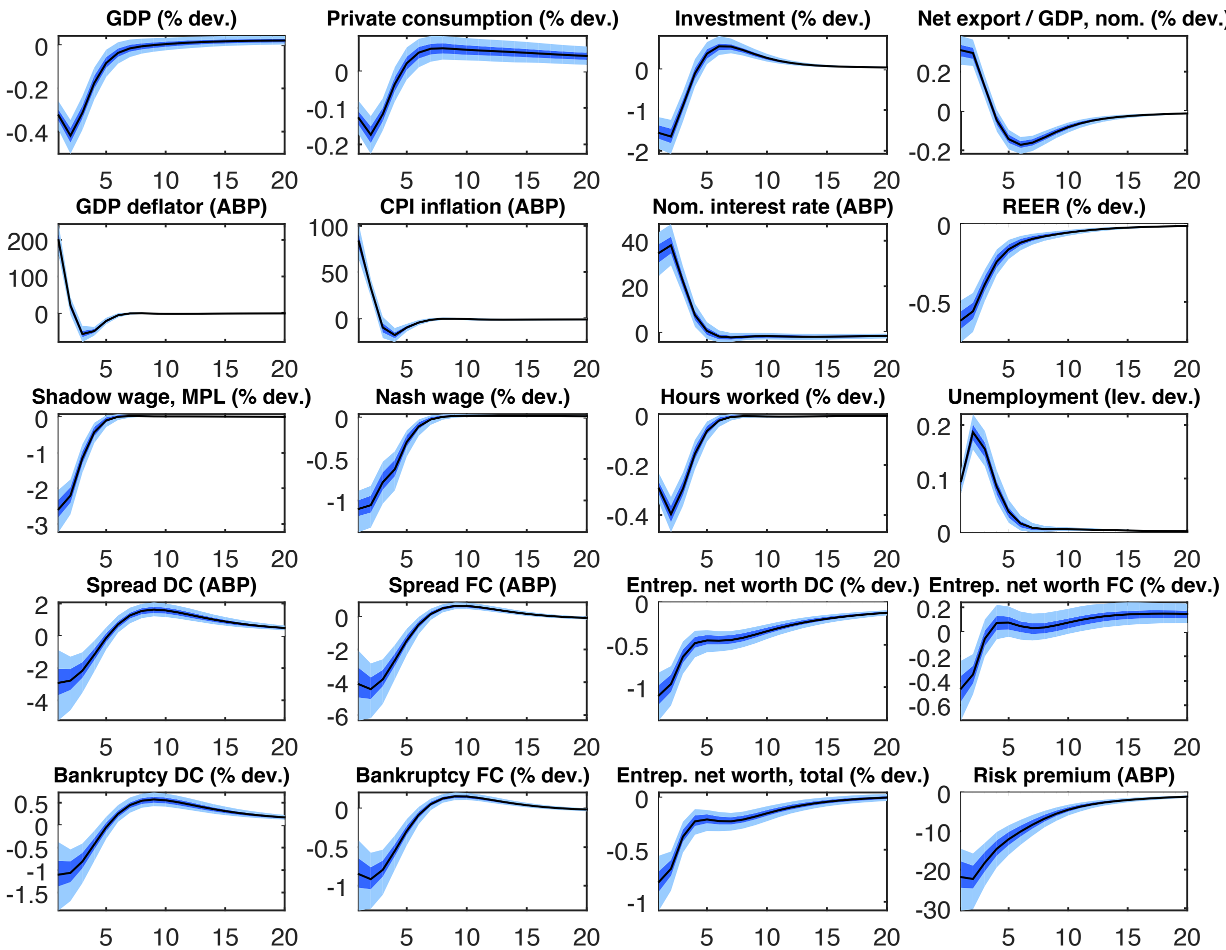
The impulse response functions to the **stationary neutral technology shock** (ϵ_t) are displayed in figure 9. This is a standard positive supply shock, with favorable effects on both output and prices. At impact, GDP increases by around 0.5 percent, gradually approaching steady state afterward. Its dynamics is driven by both internal absorption (private consumption and investment), as well as net exports. Given that the shock directly impacts the real marginal cost for domestic intermediate goods producers, this translates into a decline in domestic inflation, and to a lesser degree due to the imported component, in CPI inflation; the central bank reacts, reducing the interest rate. Despite this, the interest rate spreads for entrepreneurs increase because of the debt deflation effect generated by disinflation, and net entrepreneurial wealth falls in the first period. Given the additional effects coming from the depreciation of the exchange rate, the net worth for FC entrepreneurs registers a stronger decline relative to the similar measure for the DC ones. The higher productivity generates an increase in wages, and a decrease in total hours worked, mainly due to the the intensive margin (hours per employee). This is the result of the income effect dominating the substitution effect, given the increase in wages (households prefer to consume more leisure, even though it is relatively more expensive). The pattern of unemployment is different from the one in Christiano et al. (2011), but similar to the one from their model as implemented at the Monetary Policy Department of Riksbank by Adolfson et al. (2013). The latter argue that this pattern is generated by the positive correlation between output and employment in the data.

Figure 9: *IRFs to the stationary neutral technology shock*



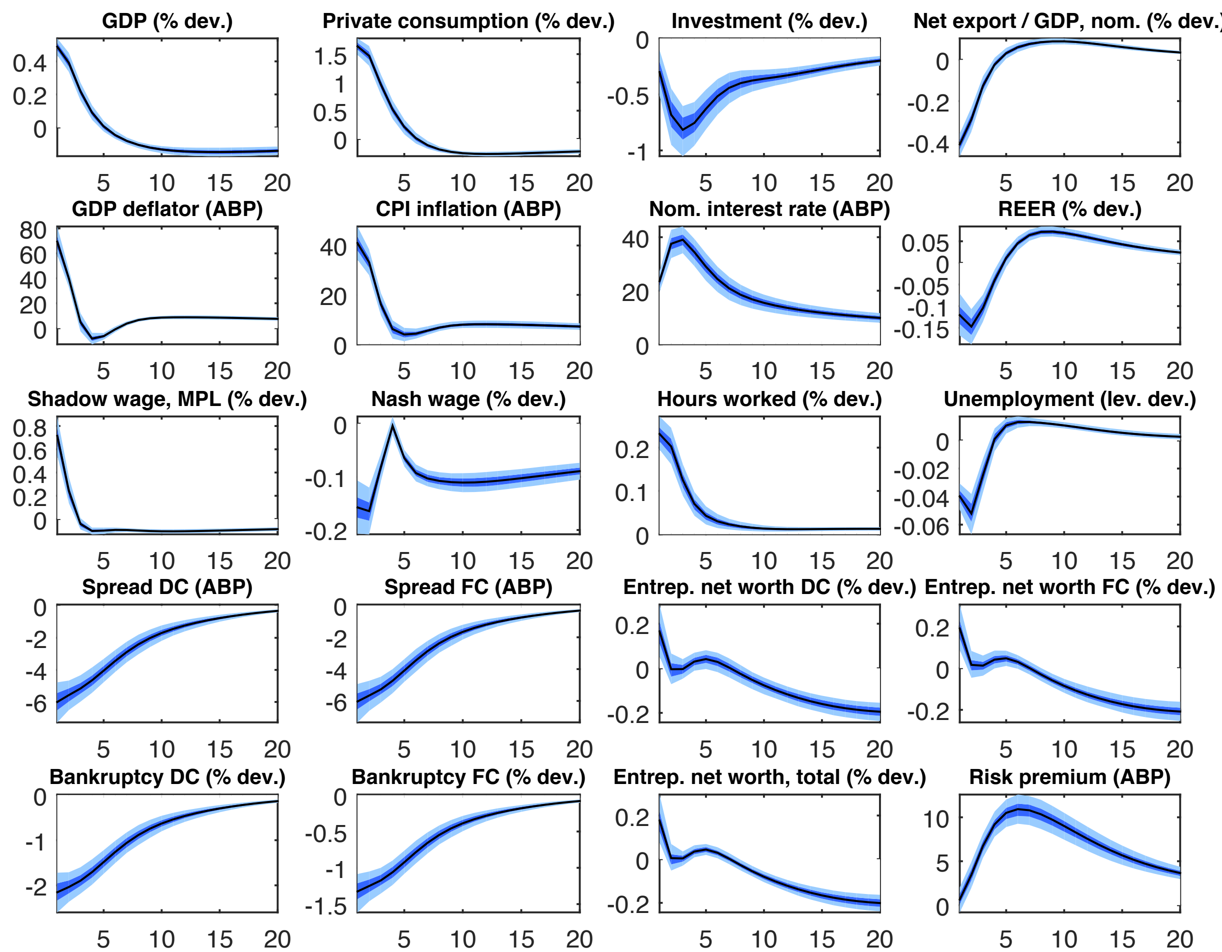
We continue by presenting the impulse response functions to the **markup shock for domestic intermediate goods producers** $\left(\tau_t^d\right)$ in figure 10, as we consider it representative for negative supply shocks. It generates an increase in prices and a decline in output. Given the imported content of consumption, the impact on CPI inflation is much smaller compared with the one on GDP deflator (around half). The deviation of CPI inflation from target prompts the central bank to increase the interest rate, which induces the exchange rate to appreciate in the first period. As before, the GDP component with the strongest response is investment, a reaction in line with the fall in net entrepreneurial worth. The appreciation of the exchange rate partially offsets the decline in the net worth of FC entrepreneurs. The decline in exports is outweighed by the movement in imports, driven by their investment component, so that overall net exports increase. Given the depressed demand for labor, total hours worked decline along with wages. The adjustment seems to be accommodated more by latter, which drop by around 1 percent at impact, compared with the former, which suffer a decrease of around 0.4 percent.

Figure 10: *IRFs to the markup shock for domestic intermediate goods producers*



The consumption preference shock (ζ_t^c) is a standard positive demand shock, and affects the trade off between the two goods entering the utility function of the household, with consumption being valued more than leisure. Consumption increases strongly being 1.5 percent higher than the steady state in the first period, but declines rapidly, reaching the equilibrium after 6 quarters. As more resources are allocated towards consumption, investment and exports registers a fall, while imports increase mainly due to higher demand for consumption goods from abroad. Nevertheless, the higher consumption dominates the evolution on investment and net exports, generating an increase in GDP with a similar pattern. The higher demand is partially accommodated through prices, and the increase in inflation prompts the central bank to react and increase the interest rate. As leisure is less valued compared to consumption, total hours worked increase, with both hours per employee and unemployment affected.

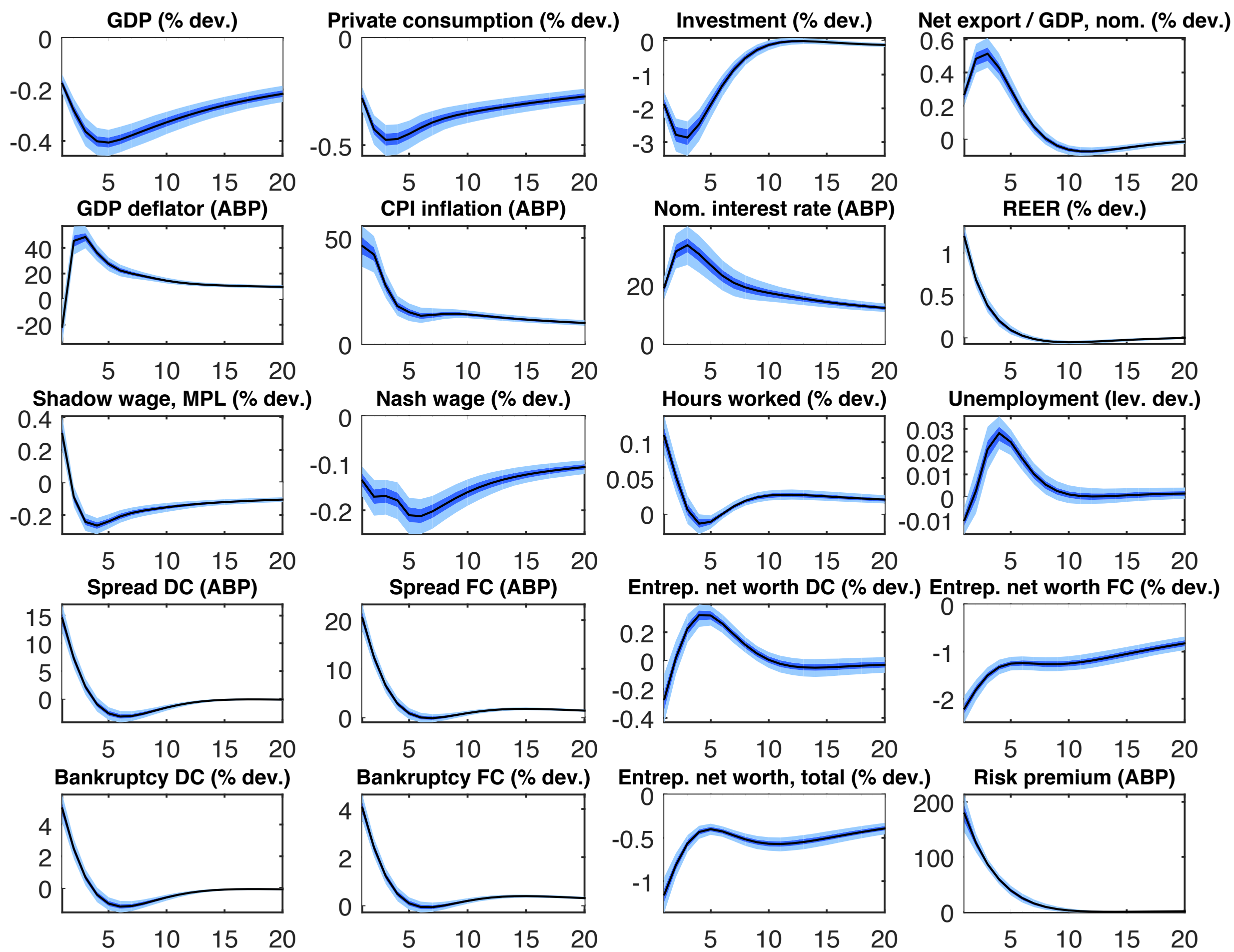
Figure 11: *IRFs to the consumption preference shock*



Following a **country risk premium shock** $\left(\tilde{\phi}_t\right)$, as illustrated in figure 12, output declines and prices increase. In standard small open economy DSGE models output increases as following a risk premium shocks, on the back of a positive evolution of net exports, stimulated by the depreciation of the exchange rate. However, in the case of emerging economies, given the presence of significant partial currency substitution, balance sheet and wealth effects can offset the effect of the depreciation on net exports, leading to lower output. We view our modification of the Christiano et al. (2011) model to allow for entrepreneurs that borrow in foreign currency as a natural extension to accommodate this stylized fact.

The shock induces a sharp, but temporary depreciation of the currency, with a corresponding response from net exports. The increase in the risk premium impacts significantly the entrepreneurs borrowing in foreign currency: the interest rate spread and interest payment surge, leading to a corresponding decline in net worth and a rise in the bankruptcy rates. The interest rate spread and bankruptcy rate increases also for the domestic currency entrepreneurs, given the reaction of the central bank to the inflation generated by the depreciation. Consequently, investment is significantly affected, falling 3 percent below it steady state level. The consumption displays a hump shaped decline with a slow converge to steady state, as the increase in interest rate provides an incentive for saving and inflation affects purchasing power. A similar pattern is observed for GDP, while investment and net exports experience faster return to equilibrium.

Figure 12: *IRFs to the country risk premium shock*

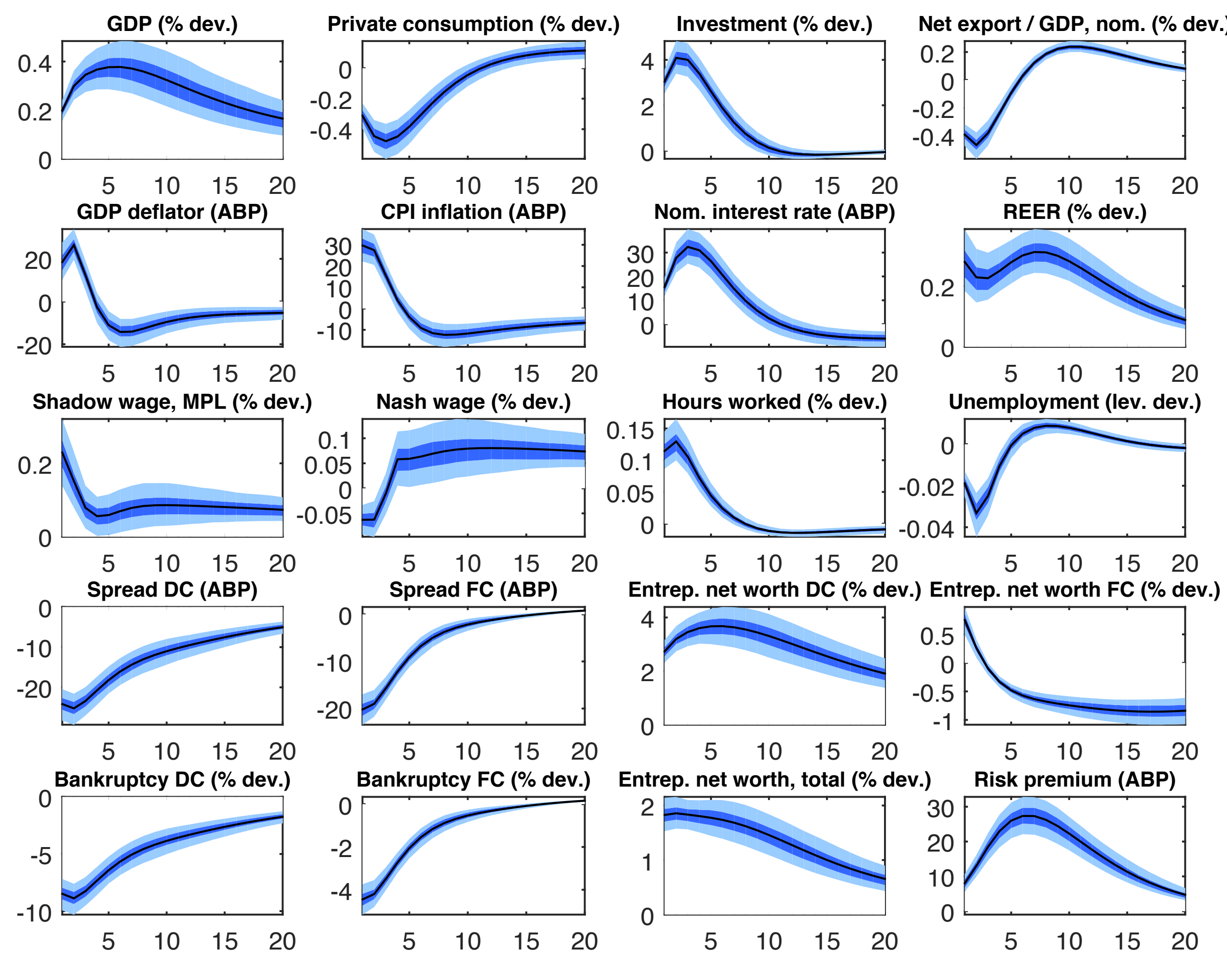


A positive **shock on the net worth for entrepreneurs borrowing in domestic currency** (γ_t^{DC}) produces a hump-shaped response of the corresponding variable, with a maximum of about 3.5 percent deviation from the steady state achieved during the second year following the shock, gradually phasing out over the simulation horizon. The reaction of foreign currency entrepreneurs net worth is favorable for the first two periods, becoming persistently negative afterward and marking a pronounced substitution effect between domestic and foreign currency funds allocated for demanding capital (and implicitly investment). However, aggregate net wealth registers a robust and continuous increase.

The two interest rate spreads decrease similarly by more than 20 ABP, given favorable initial balance sheet developments for the corresponding entrepreneurs. Consequently, the bankruptcy rates diminish, however the one associated to the domestic currency agents effect is twice more pronounced,

The shock effects on output and prices recommend it as a classical demand innovation. Accordingly, real GDP is 0.2 percent higher in the quarter the shock arises and increases to about 0.35 percent after 4 quarters, before steadily stabilizing in the long run. The GDP growth is driven by the stronger investment (4 percent higher in the second and third period following the shock), while private consumption and net exports register negative deviations from the steady states. The latter dynamics (i.e. falling net exports) occurs despite a weaker real effective exchange rate, driven by higher demand for imported investment goods. Both GDP deflator and CPI inflation rise 20 to 30 ABP initially, triggering, together with a higher output, a hump-shaped increase of the monetary policy interest rate. Total hours worked rise along both intensive and extensive margins.

Figure 13: *IRFs to the entrepreneurial net worth, DC*



4.5.3 Model moments and variance decomposition

Table 7 below presents **model moments**[48], namely means and standard deviations, versus data counterparts. Before analyzing the capacity of the model to match the standard deviations of the observed series, two remarks should be made. First, for real GDP components and inflation rates, the addition of specific trends helps perfectly matching the mean values existent in the data, with one exception: the administered prices inflation rate is recovered as a residual in order for the excess trends in administered prices and CORE1 inflation rates to add up to the CPI inflation rate (the resulted marginal discrepancy is due to assumed constant administered prices share ω_{adm}, whereas it displays some time variation in the data). Second, we demean the remaining variables (hours worked, nominal exchange rate and wages, unemployment rate, spreads, and foreign transfers) as the corresponding averages are not consistent with the model implied steady-states.

Regarding the means for hours worked, unemployment rate, foreign currency spread and nominal exchange rate (variables that do not have an excess trend), simulated 90% confidence bands[49] corresponding to the demeaned data encompass the data averages (prior to demeaning), suggesting we could use the level data without loosing much in terms of consistency. The remaining data means are outside the model-implied confidence interval, justifying the approach we follow when demeaning these.

Since we use the endogenous prior approach, some of the information regarding second moments contained in the data is fed into the estimation, allowing for an increased posterior consistency between actual and model implied variability. Nevertheless, the analysis of standard deviations reveals the model underestimates the volatility of GDP, investment and imports growth rates, and overestimates the growth of exports, while matching perfectly the private consumption dynamics. The associated confidence bands however, indicate that only the actual GDP growth volatility is significantly different from the model implied one. Despite their increased variation, the inflation rates are matched reasonably well. The model fails to generate the high volatility of investment and imports deflators observed in the data, and also the reduced administered prices inflation variability. With the exception of nominal wages and exchange rate (for which model implied standard deviation 90% confidence bands are below the corresponding data moments), the variability of the other variables are properly matched, including the ones of the actual spreads and foreign transfers which display high volatility. Overall, taking into account the dimensions of theoretical structure, short sample length of observed variables, and also high sampling uncertainty for certain variables, we assess the fit of the model as being rather decent and solid.

[48]Prices, inflation target and interest rates are presented in annualized terms, while quarterly growth rates are provided for the rest of variables.

[49]Technically, we draw 10000 independent series of length 37 (number of observations in actual sample) for each endogenous variable and compute corresponding 90% confidence bands for means and standard deviations.

Table 7: *Data and model moments (in percent)*

Romania, 2005Q3-2014Q3 (January 2015 vintage)										
Variable	Explanation	Means				**St. dev.**		Sampling uncer-tainty	90% conf. bands	
		Data	Model: Total, out of which:	BGP	Excess tnd	**Data**	**Model**		Means	St. dev.
100*ΔGDP	GDP growth	0.7	0.7	0.7	-	**1.6**	**1.2**	1.2	(0.4,1.0)	(1.0,1.5)
100*Δc	Consumption growth	0.9	0.9	0.7	0.2	**2.1**	**2.2**	1.9	(0.5,1.3)	(1.7,2.6)
100*Δi	Investment growth	0.5	0.5	0.7	-0.2	**7.7**	**6.6**	35.0	(-0.7,1.7)	(5.2,8.1)
100*Δx	Export growth	1.7	1.7	0.7	1.0	**4.4**	**5.1**	5.9	(0.9,2.5)	(4.1,6.3)
100*Δm	Import growth	1.6	1.6	0.7	0.9	**5.5**	**5.0**	10.7	(0.8,2.3)	(4.0,6.1)
400*$\bar{\pi}^c$	Inflation target	3.6	3.6	2.5	1.1	**1.1**	**1.4**	0.6	(2.1,5.1)	(0.7,1.7)
400*π^{GDP}	Domestic inflation	6.9	6.9	2.5	1.1+3.3	**7.1**	**6.6**	12.7	(3.9,9.9)	(5.2,7.8)
400*π^i	Investment inflation	6.9	6.9	2.5	1.1+3.3	**18.3**	**13.9**	66.7	(2.2,11.6)	(11.0,16.4)
400*π^x	Exports inflation	5.2	5.2	2.5	1.1+1.6	**14.4**	**13.3**	81.6	(1.9,8.6)	(10.6,16.1)
400*π^m	Imports inflation	2.8	2.8	2.5	1.1-0.8	**13.6**	**10.6**	54.7	(-0.4,6.0)	(8.4,12.8)
400*π^c	CPI inflation	4.8	4.8	2.5	1.1+1.2	**3.0**	**3.0**	2.3	(2.1,7.5)	(1.9,3.3)
400*π^{core1}	CORE1 inflation	4.4	4.4	2.5	1.1+0.8	**3.3**	**3.3**	2.7	(1.7,7.1)	(2.2,3.7)
400*π^{adm}	Adm. prices inflation	6.5	6.6	2.5	1.1+3.0	**4.9**	**7.2**	4.9	(3.0,10.1)	(5.6,8.4)
400*R	Nom. interest rate	6.8	6.8	6.8	-	**2.3**	**2.8**	2.0	(3.7,10.0)	(1.3,2.9)
100*ΔH	Total hours growth	0.04	0	0	-	**1.1**	**1.0**	0.4	(-0.1,0.1)	(0.8,1.2)
100*Δw	Nominal wage growth	2.6	1.33	1.33	-	**2.0**	**1.3**	1.1	(-0.8,0.8)	(1.0,1.5)
100*Δu	Unempl.rate growth	-0.3	0	0	-	**4.1**	**3.8**	5.1	(-0.6,0.6)	(3.0,4.8)
100*$\Delta spread^{DC}$	Spread growth DC	-3.5	0	0	-	**17.8**	**16.6**	98.7	(-2.7,2.6)	(13.5,19.9)
100*$\Delta spread^{FC}$	Spread growth FC	0.3	0	0	-	**8.4**	**10.0**	30.0	(-1.2,1.2)	(8.1,12.0)
100*$\Delta \log(S^{RON/EUR})$	Nominal ER	0.5	0	0	-	**3.2**	**2.4**	3.7	(-0.8,0.8)	(1.9,2.8)
100*Δftr	ΔFTR balance to GDP	0	0	0	-	**13.8**	**12.9**	45.7	(-1.7,1.6)	(10.4,15.6)

Variance decomposition of observed variables at 8 quarters horizon is displayed in table 8 below. We comment the results with respect to each (group of) innovation, while we also highlight the most important 3 structural shocks for each observed variable.

The shock to domestic currency entrepreneurs' net worth ($\varepsilon_{\gamma,DC}$) explains much of the variation in investment (one third), interest rate spreads (about one quarter each), imports and interest rate (close to 10% each). On the other hand, the associated foreign currency entrepreneurs shock ($\varepsilon_{\gamma,FC}$) is not important for any of the variables (no more than 1%, excepting investments). However, a closer look reveals this shock is crowded out by the risk premium innovations ($\varepsilon_{\tilde{\phi}}$), which explain much of the spreads' dynamics: about 25% and 15% for foreign and domestic currencies respectively. As the risk premium variable appears in the maximization problem of the entrepreneurs who borrow in foreign currency only, this shock is more important for this type of agents. Also, it accounts for the largest part of the exchange rate volatility (one third) and around 10% of investment, total consumer and CORE1 inflation rates. Overall, the group of financial shocks largely determine the evolution of investment, the two interest rate spreads, and exchange rate, similar to the results reported in Christiano et al. (2011). Contrary to Christiano et al. (2011) however, we obtain a much smaller cumulative contribution of these shocks to GDP growth variability, of 8% only.

There are three technology shocks in the model. The permanent technology one (ε_{μ_z}) has a limited influence on observed variables. Given the high volatility observed in the data, the model assigns a greater importance to transitory, rather than permanent technology innovations: the stationary technology shock (ε_{ϵ}) accounts for much of the GDP growth variability (20%) and also for one tenth of total consumer and CORE1 observed inflation rates. As expected, the marginal efficiency of investment (MEI) shocks (ε_{Υ}) have sizable impacts on investment and related variables, namely the two spreads.

The consumption preferences shock (ε_{ζ^c}) accounts for three quarters of real private consumption growth. It also has a noticeable contribution to GDP (over 20%), indicating the significance of demand factors for the Romanian business cycle dynamics. Other non-negligible influences of this shock relate to the interest rate, labor market variables, real imports and consumer prices inflation. Labor disutility shock (ε_{ζ^h}) is important for the hours worked only, allowing for rather limited spillovers from labor market to the other sectors.

Monetary policy shocks (ε_R) affect the inflation rates, especially the CPI and CORE1 (more than 15% of each variance explained). In line with the motivation stated previously when describing the total consumer price index disaggregation, the administered prices are not sensible to the monetary policy actions. The innovations to the Taylor rule are also important for the dynamics of investments, imports and (especially) exchange rate (about 20% of the variance explained). As the inflation rate target was not stationary but decreasing, the corresponding shock ($\varepsilon_{\bar{\pi}^c}$) has an impact on the interest rate, CPI and CORE1 inflation rates.

Regarding the markup shocks, only three of them are significant for the endogenous variables' variance decomposition. Domestic intermediate good producers markup shock (ε_{τ^d}) explains around 10% of the GDP, investment, imports, GDP deflator, CPI and CORE1 inflation rates. Also, it accounts for a large part of labour market evolutions, with more than 40% of the unemployment rate dynamics explained. The other two non-negligible shocks, export markup (ε_{τ^x}) and imports for exports markup ($\varepsilon_{\tau^{mx}}$), are particularly relevant for the imports and exports real quantities and deflators. The remained markups are important for administered prices inflation rate, due to the corresponding sector innovation (ε_{adm}).

The external sector related shocks contribute little to the variance decomposition of domestic observed variables, however among these, the effects upon exports, interest rate, nominal exchange rate, and both foreign and domestic currency spreads are somehow more pronounced.

Given increased volatility of the observed data, we allow the inclusion of measurement errors, usually using the excess trends approach of Argov et al. (2012). Ex-post these account for about 10% to 20% of the variability in most series, close to the corresponding prior standard deviations, but with large (due to increased standard deviation of the actual series) contributions to deflators (particularly the investment and GDP ones), administered prices inflation and growth of nominal wages (which inherits the variability in the GDP deflator series). However, we opted for keeping these series as observable since their inclusion results in a better matched standard deviations for some of the observables (for example, keeping the investment deflator as observable results in a more accurate match for the standard deviations of the change in spreads, the same being true for the administered prices inflation series' impact on the variability of the CPI inflation rate).

Overall, variance decomposition highlights the importance of financial shocks (the two net worth and the risk premium innovations) for investment, exchange rate and spreads dynamics. The significant contributions of consumption preferences shock to GDP and private consumption growth rates support the importance of demand-side influences. Export related markup shocks (ε_{τ^x} and $\varepsilon_{\tau^{mx}}$) essentially drive both exported and imported prices and quantities, while monetary policy related innovations, together with the domestic markup shock explain much of the consumer and CORE1 inflations. NBR interest rate and nominal RON/EUR exchange rate are largely shaped by the risk premium and Taylor rule shocks, while for labor market observed variables the labor disutility shock is relevant.

The high contributions of financial sector and export related shocks point towards the importance of both financial frictions and open economy dimension. At the same time, the effects of labor market frictions appear to be only limited.

Table 8: *Variance decomposition (%) at 8 quarters horizon of observed variables at posterior mean (top 3 structural shocks' contributions to each variable is bold)*

Shock	Description	ΔGDP	Δc	Δi	Δx	Δm	π^{GDP}	π^{c}	π^{core1}	π^{adm}	π^{i}	π^{x}	π^{m}	R	Δs	Δspr^{FC}	Δspr^{DC}	Δw	ΔH	Δu
ε_{μ_z}	Unit root tech.	2.1	1.9	0.5	0.1	0.8	0.4	1.7	1.6	0.1	0.1	0.1	0.1	3.8	0.0	0.8	0.7	**5.0**	0.1	1.4
ε_{ϵ}	Stationary tech.	**19.5**	1.4	0.5	0.9	2.8	4.3	9.8	10.7	0.5	0.4	0.5	0.3	9.1	0.6	4.0	3.6	0.7	5.9	3.7
ε_{Υ}	MEI	0.2	0.2	7.2	0.0	4.0	0.4	1.2	1.3	0.1	0.1	0.1	0.1	1.3	0.1	**14.8**	**12.2**	0.8	1.4	1.5
ε_{ζ^c}	Cons. preferences	**21.2**	**73.7**	0.7	0.3	6.7	1.6	4.6	4.9	0.3	0.2	0.2	0.3	**15.1**	0.5	2.1	1.9	2.0	**7.3**	5.1
ε_{ζ^h}	Labour disutility	3.6	0.3	0.1	0.2	0.5	0.9	2.1	2.2	0.1	0.1	0.1	0.1	2.3	0.2	0.9	0.8	3.1	**43.3**	**5.2**
ε_{R}	Monetary policy	6.9	2.2	**11.6**	1.0	**11.1**	2.5	**17.3**	**18.2**	**1.2**	**0.8**	4.8	1.9	**13.0**	**18.4**	1.8	4.0	**6.2**	3.0	**11.3**
$\varepsilon_{\bar{\pi}^c}$	Inflation target	1.0	0.2	2.0	0.1	1.6	3.0	**18.2**	**12.7**	**5.2**	**0.7**	1.3	1.4	11.8	3.6	0.6	0.9	4.9	0.3	1.3
$\varepsilon_{\tilde{\phi}}$	Risk premium	3.5	**2.3**	**13.1**	3.1	4.1	2.0	8.3	8.1	0.6	0.4	**7.8**	**2.8**	**12.0**	**33.8**	**26.9**	**13.9**	1.0	1.9	1.2
$\varepsilon_{\gamma,FC}$	FC entr. wealth	0.4	0.1	1.9	0.0	0.6	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.4	0.1	2.1	1.6	0.1	0.1	0.1
$\varepsilon_{\gamma,DC}$	DC entr. wealth	3.6	**2.9**	**29.7**	0.2	7.8	0.5	3.3	3.6	0.2	0.2	0.6	0.5	9.7	2.1	**23.7**	**29.1**	1.2	1.7	1.5
ε_{τ^d}	Markup domestic	**11.1**	0.8	9.7	**3.3**	8.5	**11.3**	**12.6**	**14.8**	0.4	**1.0**	0.7	0.3	7.1	**3.9**	1.0	0.5	**13.2**	**16.2**	**42.1**
ε_{τ^x}	Markup exports	8.7	0.7	0.2	**34.4**	**9.1**	**9.0**	1.7	2.0	0.1	0.1	**33.4**	0.1	3.0	0.6	2.3	1.8	1.3	4.6	4.8
$\varepsilon_{\tau^{mx}}$	Markup imp.exp.	2.6	0.8	0.5	**42.8**	**23.6**	**18.4**	0.8	0.8	0.1	0.1	**29.7**	**67.3**	2.1	0.7	1.0	0.7	0.1	1.1	1.0
$\varepsilon_{\tau^{\bullet}}$	Other markups	1.1	0.6	2.0	0.4	2.3	1.0	5.3	7.7	**18.8**	0.4	0.6	**3.1**	5.4	2.9	5.1	4.4	1.0	0.4	1.5
	Foreign shocks*	1.3	0.6	1.3	2.5	1.0	2.4	2.4	2.5	0.2	0.1	2.7	1.8	3.9	2.5	3.8	2.9	0.3	0.7	0.7
$\varepsilon^{\bullet,EXT}$	EXT/ME	13.2	11.3	19.2	10.7	15.5	42.4	10.7	8.5	72.3	95.5	17.6	20.1	0.0	29.9	9.1	21.2	59.0	12.0	17.7

*Include the shocks in aggregate demand, Phillips curve and Taylor rule for both Euro area and the United States, USD/EUR UIP relation shock, USD oil price shock, foreign transfers and changes in inventories shocks.

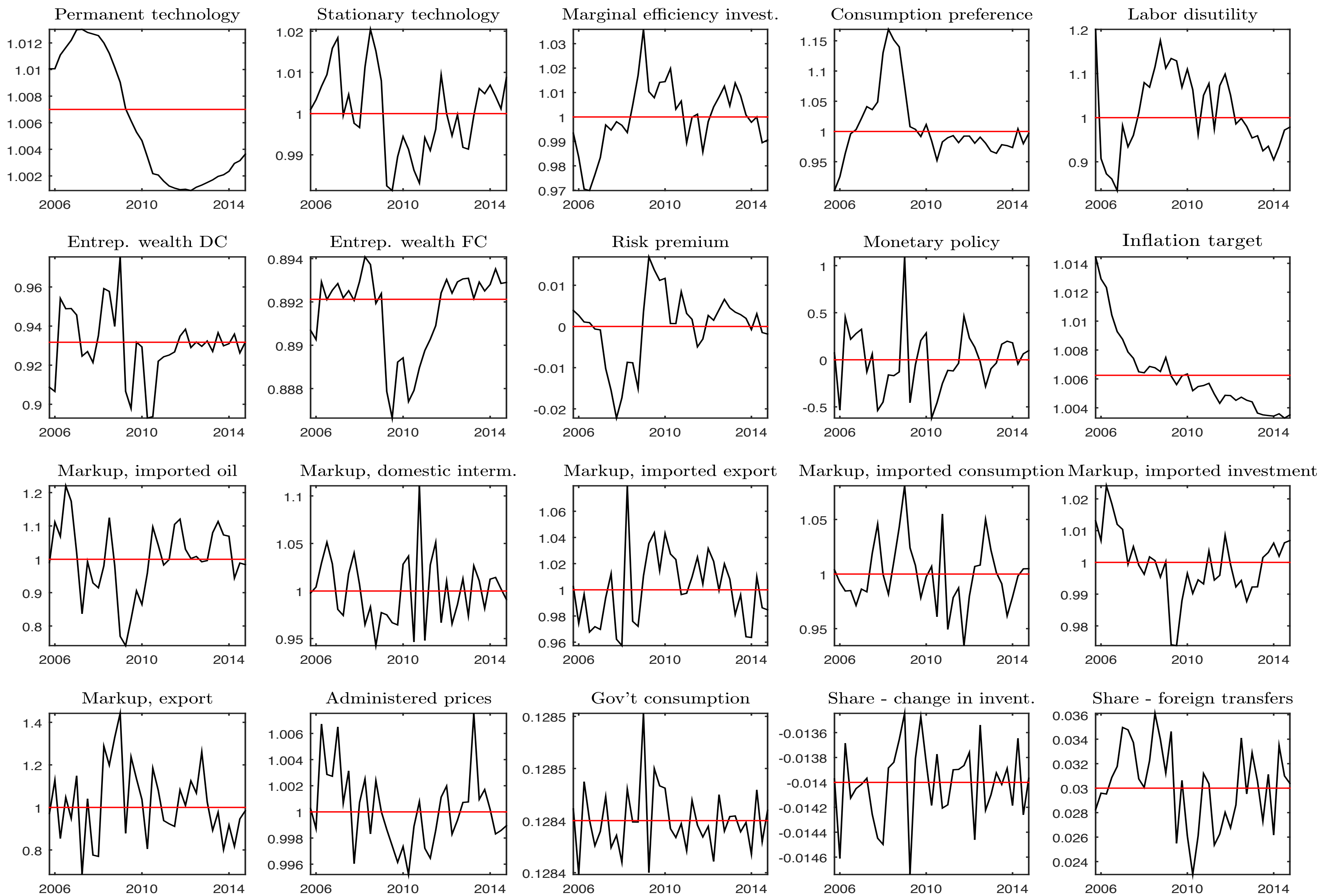
4.5.4 Smoothed shock processes and historical decomposition

In figure 14 we illustrate the **smoothed exogenous processes** as retrieved by the two-sided Kalman filter, with the red line depicting the corresponding steady state value. The distinct phases of the business cycle recorded in the analyzed period are particularly visible in the dynamics of a number of shocks. Given the AR(1) specification and the relatively high estimated corresponding coefficient, the permanent technology and, to a lesser degree, the consumption preference and the DC entrepreneurial shock processes exhibit a high degree of persistence. The sequence of positive innovations during the boom period was abruptly reversed when the global financial crisis hit the domestic economy. The subsequent slow recovery of the economy is suggested by the current positioning of these shocks below their steady state level. Substantially more volatile, the stationary (temporary) technology shock shows similar pattern with the permanent technology process, but stands above its steady state value at the end of the analyzed sample.

The magnitude of some shocks is low due to poor identification and/or crowding out by other shocks. Since we do not observe the price of oil in domestic currency but in USD, the size of the estimated markup shock for imported oil products is negligible. The markup shock for imported investment behaves similarly given the high measurement error that is assigned to the investment deflator series. Furthermore, the administered prices shock is crowded out by the domestic and imported consumption markup shocks. This is also the case for the foreign currency entrepreneurial wealth shock, with the risk premium shock most likely capturing its effects, given that both shocks affect the entrepreneurs that borrow in foreign currency, but the latter is related to more variables introduced as observables (net exports, foreign transfers) through the net foreign assets equation. The risk premium reached the minimum value in 2007Q3, but increased sharply in the aftermath of the global financial crisis until 2009Q1, subsequently lingering around its steady state value.

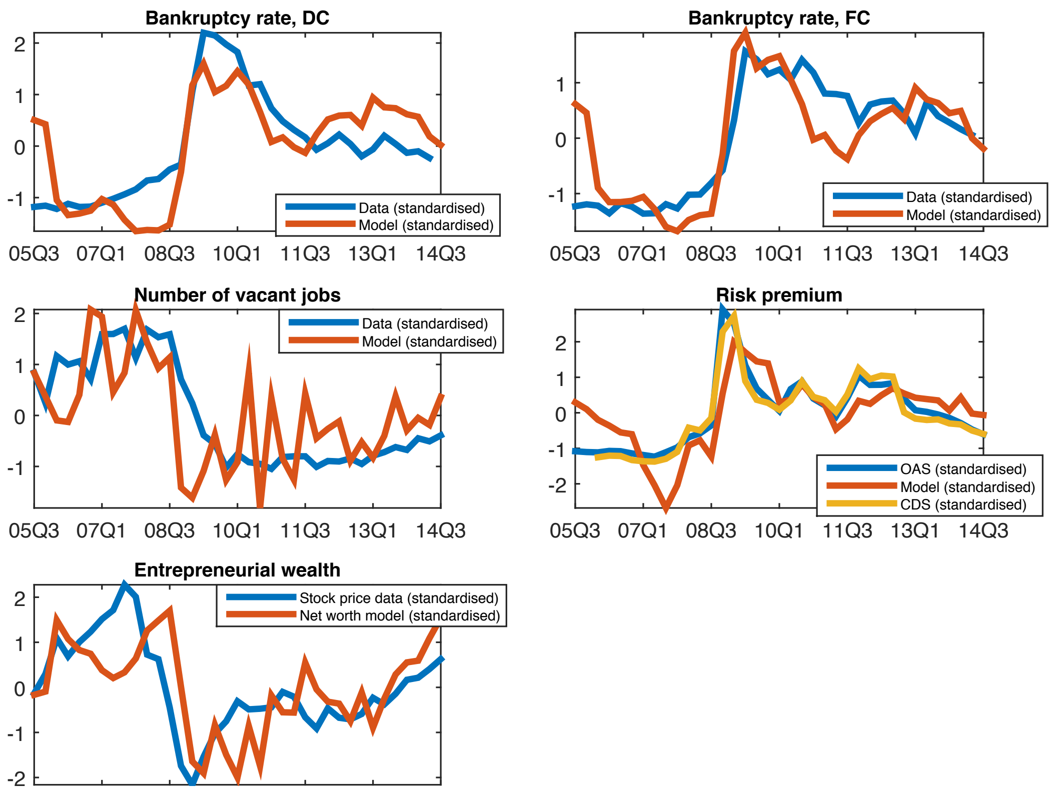
By construction of the model, CPI inflation is affected by both markup shocks for domestic intermediate goods and imported consumption goods. The relative magnitude suggests the domestic intermediate markup shock has been more important in driving inflation than the imported consumption markup shock (see also the 4.5.3 section on variance decomposition). However, given that in some preliminary estimations the relative magnitude of these shocks was inverse, we do not exclude the possibility that the shocks may not be properly identified, leading to the imported consumption markup being crowded out. It is worth mentioning that the high value of the domestic intermediate markup in 2010Q3 reflects an increase in the value added tax rate, which is constant in our model, but is visible in the CPI.

Figure 14: *Smoothed shock processes*



In figure 15 we plot the estimates for unobserved variables from the model, as retrieved by the two sided Kalman filter (smoother), against some data counterparts. To harmonize magnitudes, we standardized the variables by subtracting the average and dividing by the standard deviation. The model bankruptcy rates for entrepreneurs borrowing in domestic or financial currency display very similar patterns with data counterpart bankruptcy rates for non-financial corporations with most of their loans in either domestic or foreign currency. Also, the model captures fairly well the developments in data counterparts for the risk premium such as proxied by credit default swaps (CDS) and option adjusted spread (OAS), but is less accurate with respect to the number of vacant jobs, implying a higher volatility of this indicator as compared to the data. The evolution of the net entrepreneurial wealth is usually related to a measure of stock price. From the last row of figure 15 we can see that the Romanian stock price index BET shows a better correlation with the net wealth of foreign currency financed entrepreneurs, compared to domestic currency counterparts.

Figure 15: *Smoothed unobserved variables and data counterparts*



Next, we describe the **historical shock decomposition** of some actual and model smoothed unobserved endogenous variables during the analyzed sample using posterior mean coefficients. Starting from the vector moving-average representation of the model, any (observed or unobserved) variable can be broken down in contributions of present and past shocks, with weights assigned to previous innovations decaying in accordance to their moment of occurrence. We restrain our attention to the most important 7 shocks as measured by absolute average contribution to a variable's dynamics, storing the remained innovations in a common "Other" group. Also, due to the stochastic initialization of the Kalman filter, a distinct category of "Initial values" appears, whose contribution is usually sizable in the starting quarters, but fades out afterward. Overall, while the historical decomposition delivers conclusions similar to the variance decomposition, it also offers additional insights regarding the importance of particular shocks during specific periods.

In figure 16 we present the (steady state deviation) dynamics of GDP, private consumption, and investment expressed, both in terms of growth rates and levels.

For real GDP growth, most of the shocks had generally favorable effects during the boom period (2005-2008), with both temporary and permanent technology, consumption preferences and risk premium innovations displaying positive contributions. The crisis impact in 2008-2010 is explained by the reversed effects of the aforementioned shocks, with pronounced contributions coming from temporary technology and consumption preferences. The recovery phase features alternating contributions of the shocks (excepting systematically negative effects of the permanent technology shock, given its still below steady state value as suggested in figure 14), in line with the actual GDP growth series. Smoothed deviation of GDP from the corresponding steady state reached a maximum of about 6% in 2008, then entered negative territory following the financial crisis onset, hitting a -4% minimum during 2009-2010, and recovering afterward. Before 2009 it was driven by positive contributions from consumption preferences, risk premium, temporary technology and domestic currency entrepreneurs net worth shocks (recall from a previous discussion that most of the risk premium shock crowds out the foreign currency entrepreneurs net worth innovations). Note the importance of demand side of the model, since the corresponding shocks were dominant. Similar to actual GDP growth rate, the crisis period is explained by negative contributions of consumption preferences and technology shocks. The recent historical deviation of output from its steady state value is explained by the positive impact of the two technology shocks, while the demand-side innovations still feature adverse effects.

Private consumption dynamics, depicted in growth rates and as smoothed deviation from the corresponding steady state, acknowledges the importance of three demand-side innovations. Consumption preferences were dominant in both cases, with favorable contributions prior to the crisis and mostly negative ones since 2009 (note these are still negative in the case of consumption gap). The risk premium shock was stimulative for consumption growth during the boom phase, but reversed starting 2008Q4, once the crisis effects became visible (because of high persistence, it recorded positive, however small and hardly significant, contributions in case of the gap). The domestic currency entrepreneurs wealth shock matches the substitution effect between investments and private consumption, with counter-cyclical contributions in case of both growth rates and steady state deviation variables.

Moving to investment, risk premium, net worth and the excess trend shocks account for most of its growth rate dynamics. None of the two technology shocks that were important for both GDP and private consumption showed up, however the marginal efficiency of investment (MEI) shock dominates the supply-side contributions. Investment deviation from steady state was largely driven by the domestic currency entrepreneurs wealth and risk premium innovations, with favorable contribution in 2006-2008 and mostly negative ones since 2009.

We continue the discussion of shock decomposition with real exports and imports, as well as with the current account and net exports to GDP ratios, as shown in figure 17. Observed export growth rate was led by the exports and imports for exports markup shocks affecting the corresponding producers' real marginal costs. The latter one is likely to be important given the significant share of imported inputs in final exported goods. Turning to the exports deviation from steady state, the same two innovations are dominant. In addition, the risk premium (with negative effects in 2007-2008 and positive ones in 2009-2010) and the Euro area demand shock (with negative effects in 2009 and since 2012) appear as important. The imports for exports markup shocks are also the main source of real imports growth rate dynamics, with their alternating signs contributions mapping the evolution of actual series (similar effects display the excess trend innovations). Net worth and financial risk premium shocks were also important, but only for the latter some systematic behavior is visible (positive effects prior to the crisis, negative in 2008-2009, and mostly positive starting 2010). The two financial shocks, namely risk premium and domestic currency entrepreneurs shocks largely shape also the imports deviation from steady state. Consumption preferences also appear to have large effects, representing solid domestic demand for imported goods in 2006-2008 and a weak one since 2009.

Current account and net exports as percentages of GDP display almost identical shapes and historical decompositions, being predominantly driven by demand-side shocks, namely risk premium, net wealth, and consumption preferences. Their developments generated the corresponding large current account and trade balance deficits prior to 2009, but since the onset of the financial crisis the dynamics were inverted, thus supporting the (observed) reduction of the aforementioned deficits.

Labor market variables historical decompositions are presented in figure 18. Permanent technology shock contributed to increased wages during the boom period and had negative effects since 2009, as the productivity growth recorded below-steady state levels. Also, the domestic intermediate good producers markup shock appears as important, given that we observe (private sector) nominal wages growth rate. Labor disutility and consumption preferences shocks appear in the households' utility function and show up as determinants. Last but not least, given the high volatility of the observed series, a relatively high contribution is assigned to the corresponding measurement error. Smoothed real wages deviation from steady state was explained mostly by domestic markup and temporary technology innovations (with oftentimes offsetting effects). Other important contributions were generated by consumption preferences (generally negative), permanent technology (negative before 2011 and positive thereafter) and risk premium (putting upward pressures on wages in 2006-2009) shocks.

The unemployment rate growth was dominated by alternating evolution of specific trend, domestic markup, and temporary technology shocks, while the deviation of unemployment rate from the corresponding steady state was driven by the permanent technology one: it put downward pressures before the crisis and upward afterward. Similar effects, albeit less pronounced, were produced by consumption preferences, temporary technology and risk premium shocks, while other notable contributors were domestic markup and labor disutility innovations. Observed hours worked are explained notably by the labor disutility shock, while other significant effects come from supply-side shocks (domestic markup and temporary technology). Above steady state smoothed hours worked during 2006-2008 period were driven by labor disutility (especially in 2006-2007) and consumption preferences (especially in 2007-2008) shocks. After 2009 hours worked registered mainly below-trend evolutions, with labor disutility and permanent technology shocks as primary sources.

Historical decompositions for interest rate spreads and (nominal and real) exchange rate are presented in figure 19. Both domestic and foreign currencies spreads are mainly driven by the wealth and risk premium shocks (somehow intuitive, the former shock is more important for the domestic currency entrepreneurs, while the latter for the foreign currency agents). As the entrepreneurs are responsible for investment allocations, the marginal efficient of investment shock produces also significant effects. Both interest rate spreads deviations from steady state capture the loose credit phase during the boom period, the sudden deterioration with the onset of the financial crisis and the subsequent steady improvement that was interrupted in 2011 by the European debt crisis. Again, risk premium, wealth and MEI shocks appear as main contributors, with additional effects coming from consumption preferences and temporary technology innovations. Nominal RON/EUR exchange rate variations were determined mainly by the risk premium shock. Steady state deviation of real effective exchange rate, REER (recall EUR and USD shares are given by ω_q), displays a pronounced episode of overvaluation in 2006-2008, coming from favorable developments in risk premium, permanent technology and domestic markup shocks (domestic currency entrepreneurs net worth and temporary technology had opposite effects). Starting 2009, simultaneously with the inversion of the above mentioned shocks' effects, the REER was mostly undervalued until 2013, and stabilized around equilibrium values since then.

Finally, figure 20 plots the shock decomposition of the consumer prices inflation deviation from the corresponding target. Supply-side shocks dominate its evolution, with both temporary and permanent technology, and also domestic markup innovations, as main contributors. There are also notable upward demand-side pressures on inflation coming from positive consumption preference shock in 2006-2009, largely counterbalanced by favorable risk premium shocks that squeezed imported inflation effects.

Figure 16: *Historical decomposition (1)*

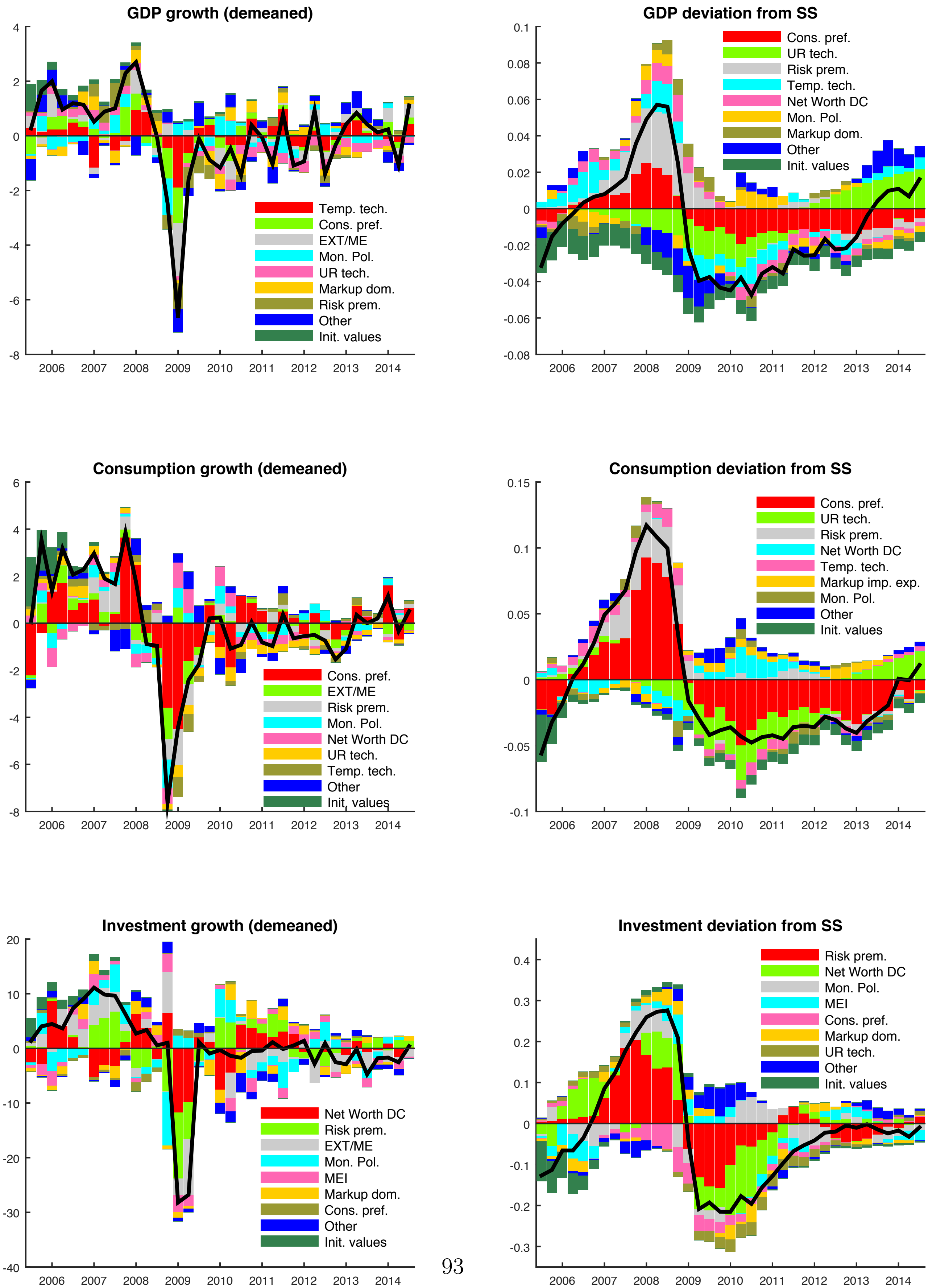


Figure 17: *Historical decomposition (2)*

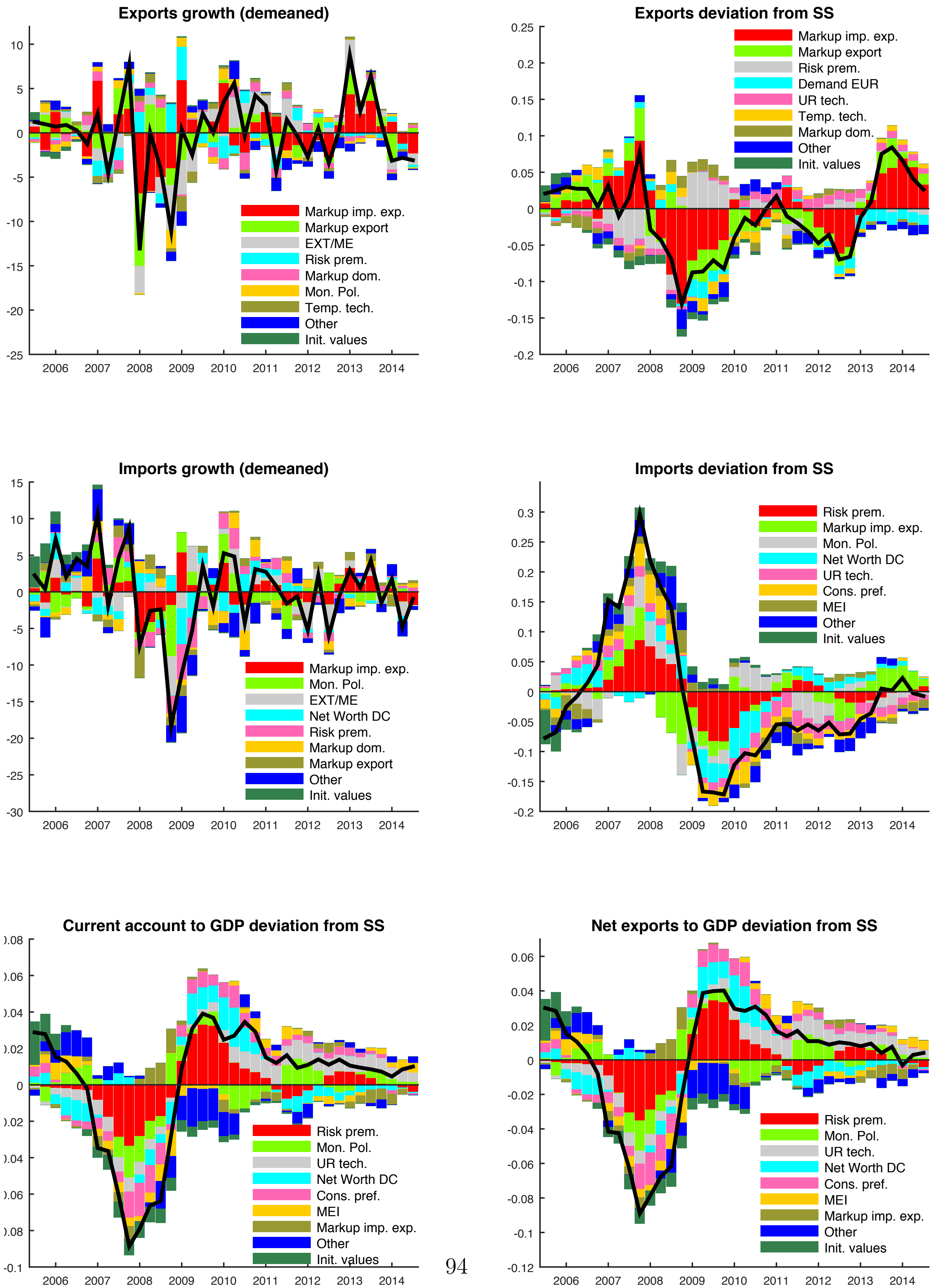


Figure 18: *Historical decomposition (3)*

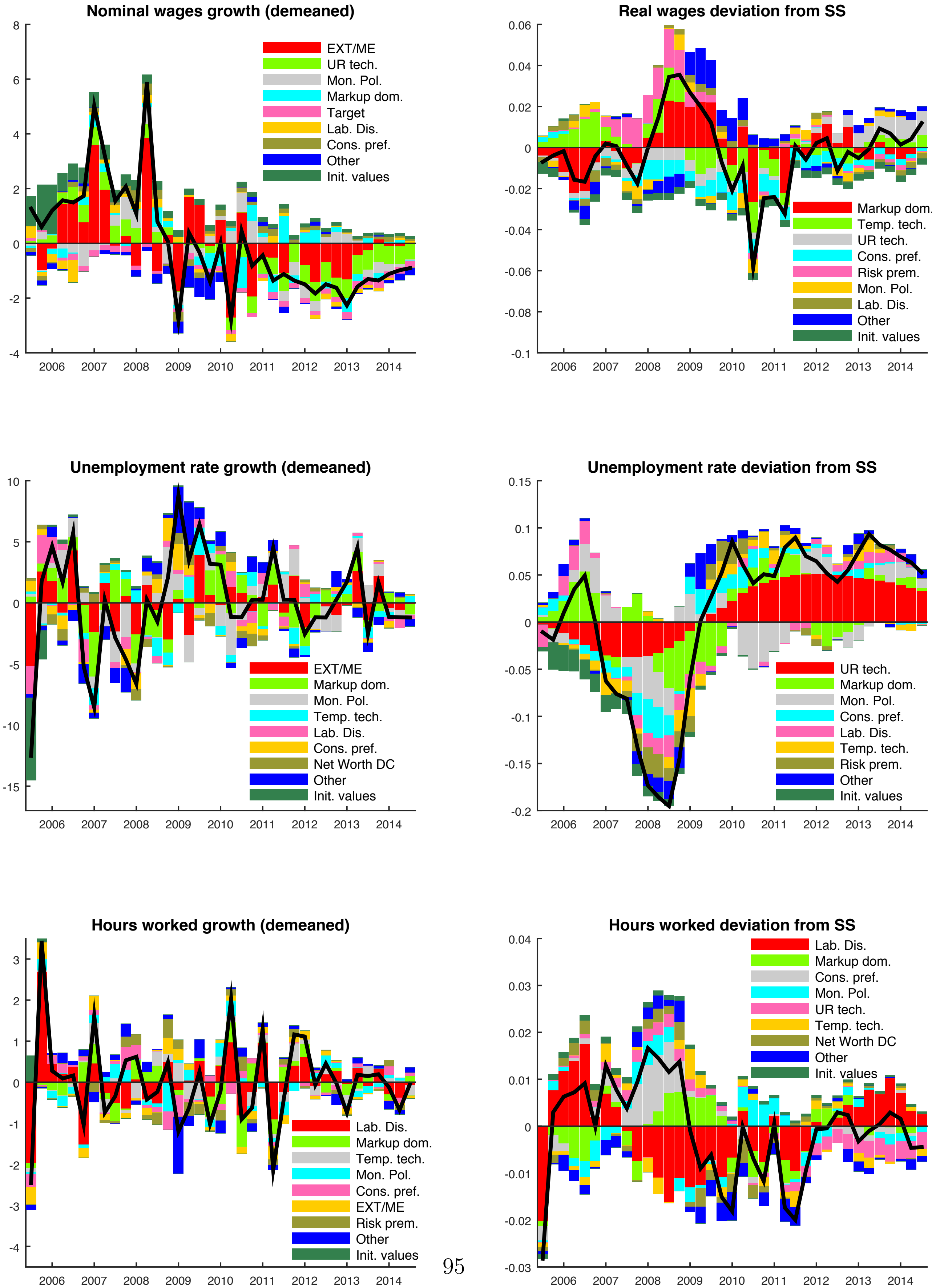


Figure 19: *Historical decomposition (4)*

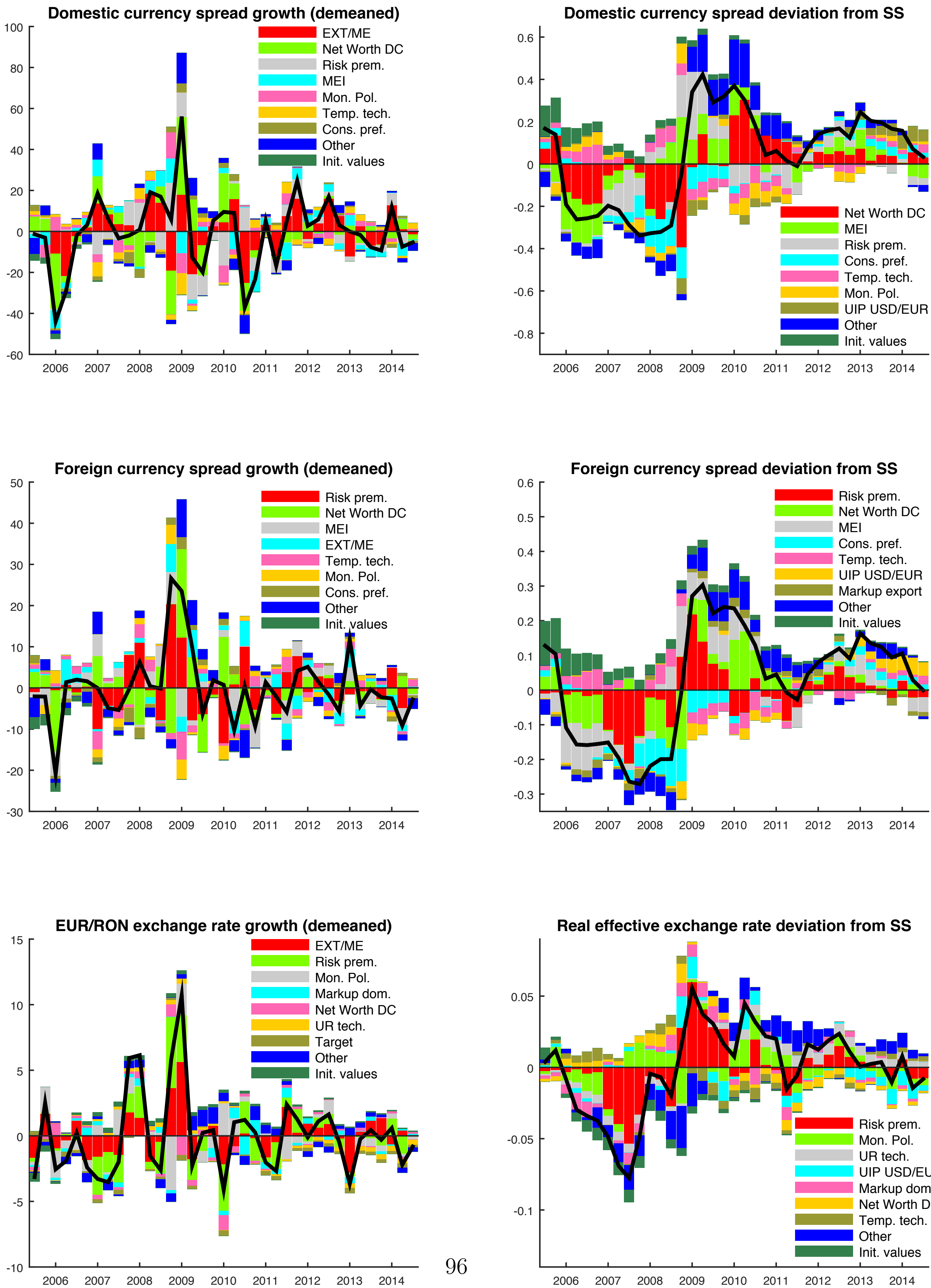
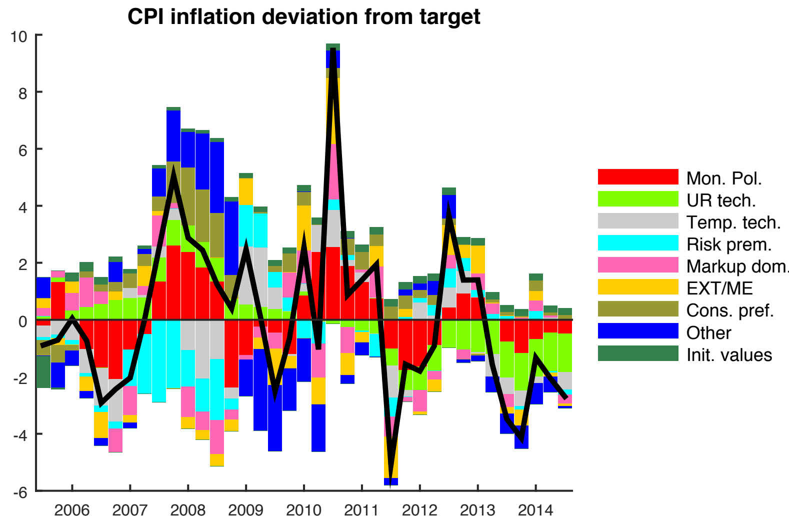


Figure 20: *Historical decomposition (5)*



4.5.5 Relative forecasting performance

There is a notable recent consolidation of efforts toward applying the DSGE models for forecasting purposes also. For the policymakers, given certain monetary policy transmission lags and the need for a forward-looking behavior, a good forecasting ability is of crucial importance. Taking into account the advantages of theoretically coherent framework embedded within the DSGE models, a good predictive capacity would render them even more appealing and powerful. Smets and Wouters (2004), Smets and Wouters (2007), Adolfson et al. (2007b), Christoffel et al. (2010), Del Negro and Schorfheide (2013) found that out-of-sample forecasting performance of the DSGE models compare quite well with some reduced-form models (like classical and Bayesian VARs, univariate, or random walk models) or professional forecasting services, and are oftentimes superior for more distant forecast horizons. These mostly favorable records are noteworthy given the unrestricted coefficient structures and data-driven estimation of the reduced-form models (unlike the DSGE models, which encompass a lot of such restrictions coming from the optimization problems of individual agents).

Here we compare the forecasting accuracy of the estimated DSGE model in relation to some time series models: random walk, univariate auto-regressions, and Bayesian VAR (BVAR) models. Since the full sample we use for estimation of the structural model is very short, a proper out-of-sample forecasting procedure that would require re-estimating it on sub-samples is not feasible. In addition, as we calibrate and match the means of the most observed variables, including via the excess trend components, an estimation on different sample would require additional re-specifications of the model.[50] As such, we perform an in-sample unconditional point forecasting exercise using estimated full sample posterior means

[50] Christoffel et al. (2010) argue that the balanced growth path inherent in their DSGE model is not consistent with the observed growth rates, leading to persistently negative or positive forecast errors. Using the excess trend components we avoid this problem.

of the coefficients. We are aware that this strategy is not genuinely accurate, but it can still shed some light and provide indicative results regarding the model's forecasting capacity. For a meaningful comparison, we apply the same approach to the competing models, i.e. we use full sample estimated coefficients instead of estimating individual models for each forecasting round. The hold-out sample consists of 2010Q1:2014Q3 observations, meaning that the first forecasting round contains up-to-and-including 2009Q4 data, while the forecasting horizons cover one to eight quarters-ahead predictions.

We now briefly describe the set of competing models. Random walk (RW) specification assumes a no-change forecast at any point. This is expected to provide reasonable accuracy for the NBR interest rate forecasts, given there are long episodes during which the policy interest rate was kept unchanged. The univariate first order auto-regression model, labeled AR(1), is usually used as benchmark in relative forecasting performance exercises, and does not explore any interrelations between the variables.

The record of Bayesian VAR improved predictive accuracy is relatively large, as surveyed in Karlsson (2013). Similarly to Adolfson et al. (2007b) and Christoffel et al. (2010), we use 4 lags and employ a Minnesota style prior for the coefficients and a diffuse one for the residuals covariance matrix, while for approximating the posterior distribution (given a closed-form solution is not available) we apply a version of Gibbs sampler described in Karlsson (2013) with 150.000 draws, out of which 50.000 are burned. For actual in-sample forecasting procedure we use the posterior mean of the coefficients. We adopt a 0.5 prior mean, to assign some a priori persistence for each endogenous variable, while the overall tightness is set to 0.3, foreign lags tightness to 0.2, and lag decays hyperparameter to 1, as in Adolfson et al. (2007b)[51].

In order to disentangle the separate contribution of open economy dimension, and labor and financial markets variables, we estimate two BVAR models which differ only with respect to the data set. The smaller one (labeled BVAR3) consists of three variables only: GDP growth, CPI inflation rate, and interest rate. The larger one (labeled BVAR6) comprises three additional series: growth rates of unemployment rate, nominal RON/EUR exchange rate, and domestic currency interest rate spread. Note that the variables are fed into the models in the forms specified when linking the DSGE model endogenous variables to their data counterparts in measurement equations.

Aside from familiar root mean squared error (RMSE) statistics for each endogenous variable, we compute also two multivariate forecasting performance indicators. These are based on h-step-ahead scaled mean square error (MSE) matrix[52], taking into account the correlation structure of the individual variables forecast errors. Log determinant statistic and trace statistic of the scaled MSE matrix are calculated and used as scalar values for the multivariate forecasting performance. Following Adolfson et al. (2007b) and Christoffel et al. (2010), we highlight that the trace is predominantly driven by the largest eigenvalue of the MSE matrix, which represents the dimension in which a model is least predictable, while the log determinant is mostly driven by the smallest eigenvalue, or by the most predictable dimension. As such, these statistics face the danger of being dominated by a single variable

[51] See Litterman (1986) for a description of Minnesota style prior.

[52] Similar to Adolfson et al. (2007b) and Christoffel et al. (2010), the scaling is performed using a diagonal matrix with sample variances for each series as diagonal elements.

Table 9: *Relative forecasting performance (selected forecast horizons).*
RMSE are expressed as ratios to DSGE-based RMSE and log determinant and trace statistics are expressed as difference from the DSGE-based statistics. Cases in which DSGE model performs better are bold.

	RMSE						Multivariate statistics			
	GDP	CPI	Inter.	Unem.	Exch.	Spread	3 variables set		6 variables set	
	growth	infl.	rate	rate	rate	DC	Log det.	Trace	Log det.	Trace
1q										
RW	**1.23**	**1.22**	0.94	0.96	**1.45**	**1.20**	**0.99**	**0.83**	**1.97**	**1.47**
AR(1)	0.98	**1.00**	0.88	0.70	**1.05**	0.92	-0.05	-0.07	-1.07	-0.43
BVAR3	0.94	0.69	0.54	—	—	—	-2.05	-0.90	—	—
BVAR6	0.65	0.57	0.45	0.59	0.88	0.76	-3.82	-1.32	-6.21	-2.07
2q										
RW	**1.09**	**1.21**	**1.09**	**1.05**	**1.82**	**1.52**	**0.93**	**0.74**	**2.69**	**2.29**
AR(1)	0.83	**1.03**	**1.00**	0.72	**1.03**	**1.01**	-0.24	-0.04	-0.63	-0.24
BVAR3	0.83	0.66	0.55	—	—	—	-2.38	-1.07	—	—
BVAR6	0.85	0.61	0.52	0.62	**1.10**	0.83	-3.43	-1.16	-4.51	-1.60
4q										
RW	**1.69**	**1.64**	0.93	**1.49**	**1.46**	**1.94**	**3.04**	**2.56**	**4.91**	**4.45**
AR(1)	**1.02**	0.91	0.92	0.89	**1.06**	**1.04**	**0.67**	-0.26	**0.36**	-0.26
BVAR3	**1.06**	0.60	0.65	—	—	—	-0.90	-0.97	—	—
BVAR6	0.95	0.57	0.71	0.86	**1.04**	0.92	-1.41	-1.06	-2.08	-1.20
8q										
RW	**1.44**	**1.04**	0.65	**1.10**	**1.39**	**2.16**	**0.34**	-0.27	**2.67**	**1.46**
AR(1)	0.95	0.89	0.65	**1.07**	**1.01**	0.98	-1.08	-1.04	-1.03	-1.02
BVAR3	0.86	0.63	0.46	—	—	—	-2.05	-1.87	—	—
BVAR6	0.89	0.64	0.48	**1.03**	**1.04**	0.85	-2.25	-1.82	-3.04	-1.90

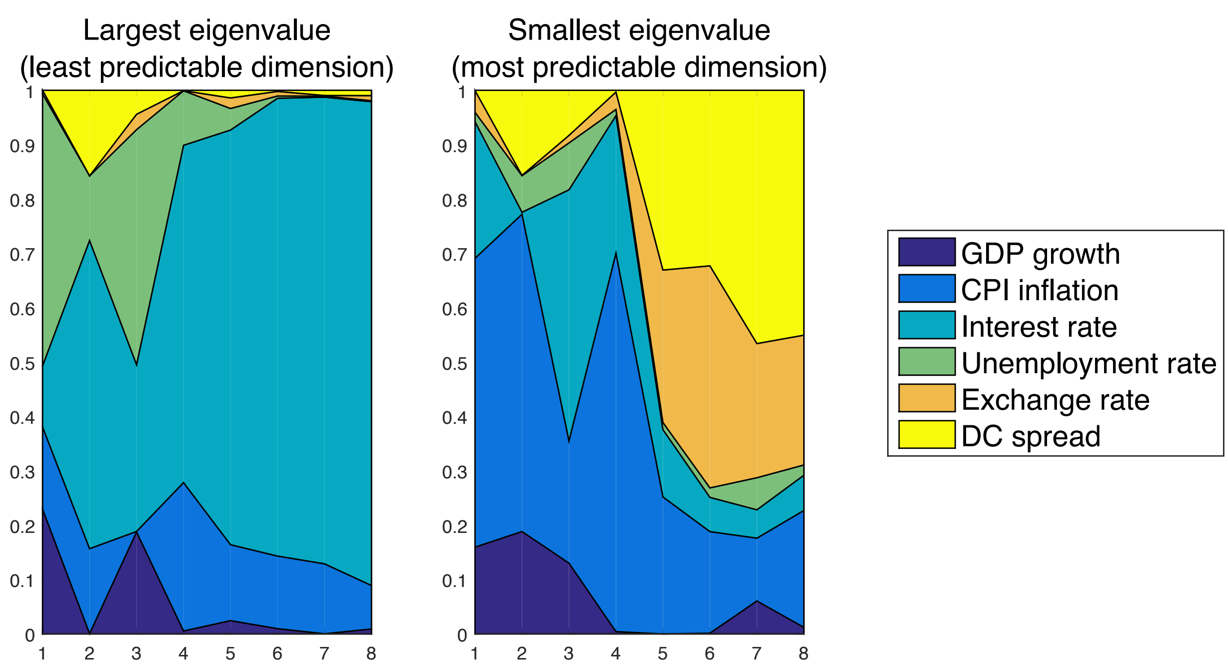
(for which the forecasts are either very accurate, or very imprecise).

We start with commenting on relative to the DSGE model RMSE statistics presented in table 9. A higher than 1 entry indicates the DSGE performs better for that variable and forecasting horizon. Nominal exchange rate is the variable the DSGE model is most successful, losing only to BVAR6 at 1-quarter-ahead forecast horizon. The in-sample accuracy of GDP, unemployment rate and domestic currency spread forecasts is worse when compared to the reduced-form models (especially the 6-variable BVAR), but is overall satisfactory, particularly at longer forecast horizons. This last result is compatible with the other papers referred to above. The interest rate DSGE forecasts are the least accurate, more so against the BVAR models. Overall, the DSGE model usually performs better than the RW and similar to the AR(1) models, but is generally worse than the two BVARs (excepting the exchange rate forecasts). Previous results in Smets and Wouters (2004), Smets and Wouters (2007), Adolfson et al. (2007b), Christoffel et al. (2010) concluded that the DSGE-based out-of-sample forecasts are usually as accurate as BVAR ones, and oftentimes even better. The results we presented here are not entirely consistent with those evidences, but it is important to take into account that due to a very short sample we performed only an in-sample forecasting exercise using the coefficients' posterior means (for all the competing models). In addition, when using the DSGE model on a regular basis, the forecasting procedure would be applied on real-time data and (possibly) conditioning on a certain exogenously determined paths for some variables (like interest rate or external sector variables), as presented in Del Negro and Schorfheide (2013).

Multivariate forecasting performance indicators are presented also in table 9 with respect to the BVAR3 and BVAR6 variable sets, as described above. Again, these are declared as differences from the DSGE corresponding statistics, such that a positive entry implies more accurate overall forecasts. As resulted from the RMSE analysis above, log determinant and trace statistics confirm the DSGE model is superior to the RW model and is similar to the AR(1) model. When compared to BVAR3 and BVAR6 models, it performs relatively worse, but the statistics point the difference in favor of the former are not so impressive at longer forecasting horizons (starting four quarters-ahead).

Following Adolfson et al. (2007b), we make an attempt at analyzing the 6-variable data set MSE matrix associated to the DSGE model using a singular value decomposition. More precisely, we decompose the largest and smallest eigenvalues, which account for the least and most predictable linear combination of individual variables respectively, into contributions coming from each variable forecast error according to the associated eigenvectors. Figure 21 displays these breakdowns for one to eight quarters-ahead MSE matrices. The least predictable dimension (left subplot) is dominated at short forecast horizons by unemployment

Figure 21: *Largest and smallest MSE matrices eigenvalues decompositions.*



rate and interest rate large forecast errors, while the longer horizons are mostly explained by the interest rate alone. As such, the DSGE model is overall less successful in forecasting these two variables (relatively to the other variables). Also, it is noticeable the almost nonexistent share of exchange rate, as suggested by favorable RMSE above, and also good record for GDP growth and spread predictions, especially at beyond four quarters-ahead forecasts. Turning to the most predictable dimension (right subplot), at short-term horizons it is driven by good relative performance of inflation rate forecasts, while at longer horizons by spread and exchange rate forecasts as well. The two subplots are not entirely an opposite of each other, as one can expect (since a bad ability to forecast a certain variable should show up as a larger area in left subplot and a smaller area in the right subplot), but overall the conclusions are fairly consistent with the univariate and multivariate indicators documented above.

4.5.6 Monetary policy abroad: when ECB and FED move in opposite directions

This subsection presents the impact of an scenario in which Euribor and the federal funds rate (FFR) move in opposite directions. Namely, we simulate a 25 basis points (1 percentage point in terms of the annualized interest rate) unanticipated decrease in Euribor rate, simultaneous with a similar in magnitude increase in FFR. Although we are aware that the simulations start from the steady-state, we want to capture the possible impact of near term expected developments in external interest rates[53].

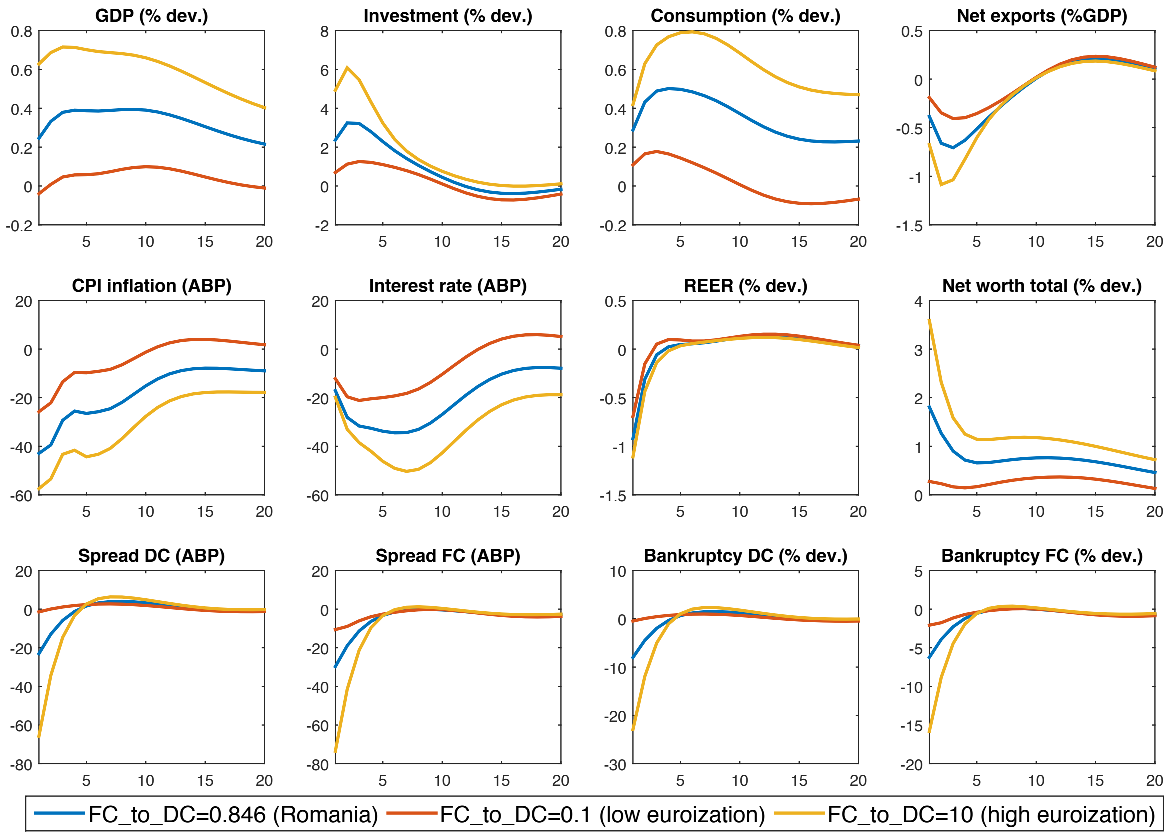
As noted previously, the structure of the external sector assumes that:

- trade in goods and services takes place in both EUR and USD. In our case, the weight of trade transactions taking place in EUR for the 2006-2014 period is given by $\omega_q = 72.6\%$, with $(1 - \omega_q)$ representing the USD denominated transactions corresponding share;
- foreign currency financial transactions (i.e. loans to entrepreneurs borrowing in foreign currency) take place *only* in EUR, with a mass of $(1 - \omega_k)$ entrepreneurs accessing such loans.

As such, changes in the external sector variables affect the domestic economy through different channels: while a shock hitting the US economy *directly* influences the domestic variables via the net exports channel, a shock to the Euro area economy has a *direct* impact both through the net exports *and* the balance sheet channels (through the EUR denominated loans taken by part of the entrepreneurs). In our simulation, we expect that the importance of the latter mentioned channel to positively depend on the euroization degree of the domestic economy. Therefore, we vary the degree of euroization of the economy as measured by the ratio of foreign (i.e. EUR in our model) to domestic currency denominated loans. The benchmark value used in the baseline model for Romania is 0.846 (i.e. around 45% of total loans are in EUR), while we consider also values corresponding to a low (i.e. around 10% of total loans are in EUR) and high (i.e. around 90% of total loans are in EUR) euroization degrees. Since we calibrate the share of entrepreneurs that borrow in domestic currency

[53] While we are aware the interest rates in the Euro zone are (close) to the zero lower bound, we proxy in the model the recently announced QE program by an interest rates decline.

Figure 22: *Impulse response functions*



(and implicitly those that borrow in EUR) in order to match the empirical ratio of foreign to domestic currency denominated loans, by varying the latter, we implicitly change the shares of entrepreneurs that borrow funds denominated in a certain currency (i.e. we change ω_k). The results are presented in figure 22.

The shocks on foreign interest rates (i.e. a decrease in Euribor and a simultaneous increase in FFR) cause a depreciation of the EUR vis-a-vis the USD. The US output and inflation rates decline following an increase in the FFR. While, as expected Euro area inflation rate increases after a decline in Euribor rate, the output declines given the strong estimated foreign demand channel (the depreciation of the EUR and the decline in the real interest rate are outweighed by the effect of lower external demand coming from US)[54]. As a result, the aggregate effective foreign output, a variable that enters the equation reflecting the foreign demand of domestic (Romanian in our case) exports of goods and services, declines. The same happens with the aggregate effective foreign inflation rate, given the high decrease in the US measure.

Turning to the local economy, the real effective exchange rate appreciates with the price

[54] The estimated impact of foreign demand (i.e. US in our case) on Euro area output is significantly stronger than the corresponding US demand for Euro area exports, as one can observe from the estimated parameters presented in table 13 from Appendix.

effect on net exports being augmented by the volume effect (the fall in effective external demand). The impact of the trade channel is reflected in a decline in the net exports to GDP ratio that is larger the higher is the degree of the euroization of the domestic economy. This latter aspect is mostly the result of a higher demand for imported investment goods.

The decrease in the EURIBOR interest rate leads to substantially stronger balance sheet effects reflected in higher investment and a increase in output when euroization is higher. The effect of the foreign interest rate decline outweighs the negative impact of nominal depreciation of the RON/EUR exchange rate that occurs after an initial appreciation.

Following the decrease of import prices, more pronounced in a higher euroized economy, the CPI inflation decreases. This leads, given the stronger reaction of the monetary authority to inflation deviation relative to the output one, to a decline in the domestic nominal interest rate, with a positive impact on domestic consumption.

Given the effects of the decrease in both domestic and Euribor interest rates, the financial accelerator effect dominates the adverse debt deflation channel. The decreased bankruptcy rates are translated in lower interest rate spreads on corporate loans, contributing to the increase in net worth. Again the effects are stronger for a higher degree of euroization.

4.6 Alternative models

We compare the estimated model, as presented in the previous sections, with two alternative specification: the first one *(Alternative 1)* is the main model estimated without endogenous priors, while the second one *(Alternative 2)* differs only with respect to the Taylor rule used. Namely, we specify a Taylor rule in which the monetary authority, besides the current deviation of output from its steady state value, responds to the deviation of the 4 quarters ahead expected annual inflation (i.e. $\frac{\pi^c_{t+4}+\pi^c_{t+3}+\pi^c_{t+2}+\pi^c_{t+1}}{4}$) from the corresponding target. In estimating all three models, we use for the exogenously estimated external sector the results associated with the baseline specification[55].

When looking at the differences, we focus on the following two dimensions: standard deviations matching and impulse response functions. At least the following two observations emerge:

- There is a tendency in the no endogenous priors model of generating higher model implied standard deviations relative to the ones observed in the data (see table 10). This is especially the case for inflation rates, nominal interest rate, change in nominal wages and variations in spreads. This is also true when the baseline specification is used as a benchmark, with the exception of change in real GDP, for which the *Alternative 1* matches a volatility closer to the one present in the data.

- The *Alternative 2* model, that uses a modified Taylor rule, has a relatively similar performance as the baseline specification in terms of matching the standard deviation of the observed series (even more so when one also take into account the sampling

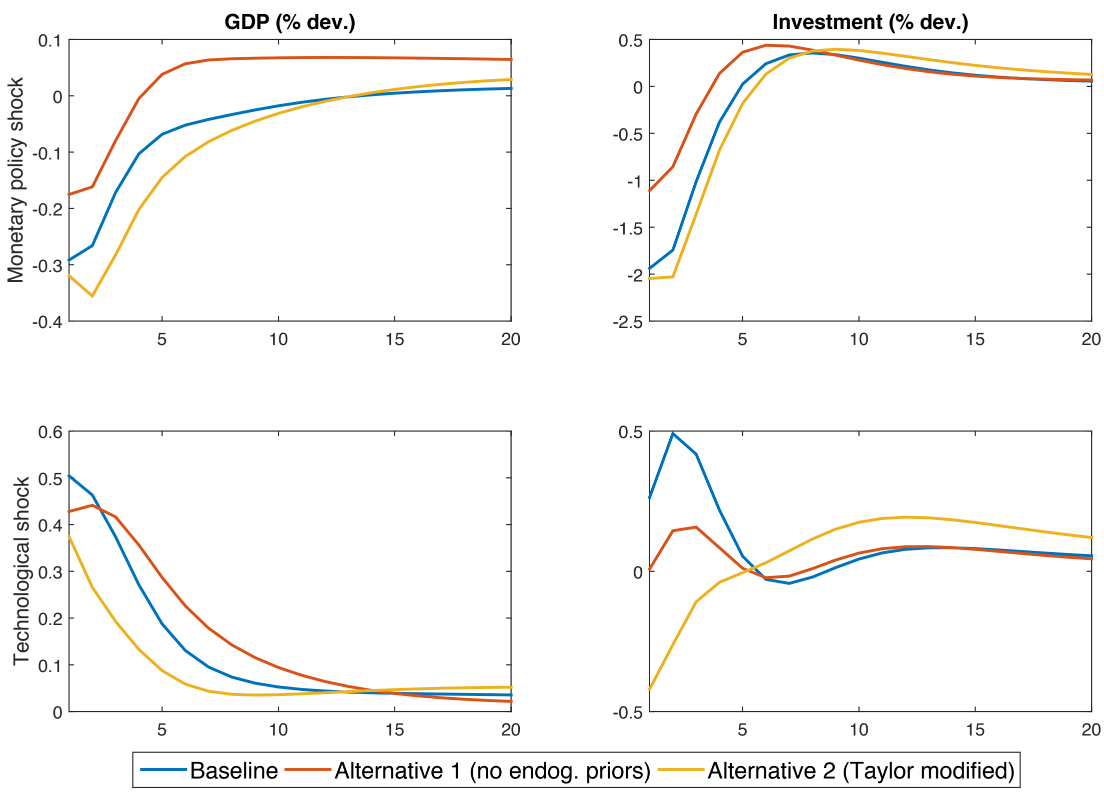
[55]The results presented here use, for each model, the mean values of the parameters based on single Metropolis chain with 400,000 draws, after a burn in period of 200,000 draws. The acceptance rates were 0.2368 for *Alternative 1,* 0.2487 for *Alternative 2* and 0.2389 for the baseline model.

Table 10: *Data and moments (%) - baseline versus alternative models*

Romania, 2005Q3-2014Q3 (January 2015 vintage)						
Variable	Explanation	St. dev.				Sampling uncertainty
		Data	Baseline	Alternative 1	Alternative 2	
				No endog. priors	Taylor modified	
100*ΔGDP	GDP growth	1.6	1.2	1.5	1.2	1.2
100*Δc	Consumption growth	2.1	2.2	2.1	2.2	1.9
100*Δi	Investment growth	7.7	6.6	8.2	6.0	35.0
100*Δx	Export growth	4.4	5.1	5.8	5.6	5.9
100*Δm	Import growth	5.5	5.0	5.8	5.3	10.7
400*$\bar{\pi}^c$	Inflation target	1.1	1.4	0.9	1.4	0.6
400*π^{GDP}	Domestic inflation	7.1	6.6	13.4	6.9	12.7
400*π^i	Investment inflation	18.3	13.9	16.2	13.9	66.7
400*π^x	Exports inflation	14.4	13.3	21.0	14.8	81.6
400*π^m	Imports inflation	13.6	10.6	21.6	11.8	54.7
400*π^c	CPI inflation	3.0	3.0	12.0	3.5	2.3
400*π^{core1}	CORE1 inflation	3.3	3.3	12.5	3.9	2.7
400*π^{adm}	Adm. prices inflation	4.9	7.2	14.7	7.3	4.9
400*R	Nom. interest rate	2.3	2.8	13.6	2.8	2.0
100*ΔH	Total hours growth	1.1	1.0	1.3	1.0	0.4
100*Δw	Nominal wage growth	2.0	1.3	3.8	1.5	1.1
100*Δu	Unempl.rate growth	4.1	3.8	6.6	4.0	5.1
100*$\Delta spread^{DC}$	Spread growth DC	17.8	16.6	32.4	16.2	98.7
100*$\Delta spread^{FC}$	Spread growth FC	8.4	10.0	13.9	10.0	30.0
100*$\Delta \log(S^{RON/EUR})$	Nominal ER	3.2	2.4	4.8	2.6	3.7
100*Δftr	ΔFTR balance to GDP	13.8	12.9	13.9	13.5	45.7

uncertainty measure). However, we prefer the baseline given: its (slightly) better performance in terms of matching CPI and CORE1 inflation rates' volatilities and the shape of the impulse response function of investment to a temporary technological shock, as illustrated in figure 23. Regarding the latter fact, in the *Alternative 2* model, investment falls following a temporary technological shock, while it increases in the baseline specification. The reason for the drop in investment is similar with the one mentioned by Christiano et al. (2011) when a Taylor rule reacting to lagged inflation is used in the presence of nominal debt contracts for entrepreneurs. Namely, in the *Alternative 2* model, except the first quarter, the fall in inflation is stronger and more persistent, as the monetary policy reacts each period to 4 quarters ahead expected annual inflation, which, given the return of inflation to its steady state value from below, is smaller than the current period inflation rate. Thus, in the *Alternative 2* model, the initial reaction of the interest rate is not strong enough to outweigh the surprise disinflation that affects investment through the debt inflation channel.

Figure 23: *IRFs in baseline and alternative models*



5 Conclusions

In this paper we described a DSGE model developed and estimated for Romania. Our work built on the model of Christiano et al. (2011) which incorporated, in a standard new Keynesian small open economy framework, financial and labor market frictions as elements deemed necessary in understanding business cycle fluctuations after the recent global financial crisis. Furthermore, the model was enriched along several dimensions to account for the specific features of the Romanian economy, considered relevant.

Therefore, to accommodate the existence of a significant share of foreign currency (EUR) denominated loans in the local economy we adapted the financial sector to include two types of entrepreneurs, according to the currency in which they borrow funds. This extension allows us to better capture the effects of the exchange rate on GDP: besides the usual positive impact on net exports, a nominal depreciation of the domestic currency vis-a-vis EUR leads to a balance sheet effect, that is more pronounced the higher is the euroization degree (i.e. the higher is the share of entrepreneurs taking loans in EUR relative to those using domestic currency loans).

Furthermore, the production sector has been modified to include oil as an input for domestic intermediate goods. We proceeded to diss-aggregate the consumer prices into CORE1 and administered prices, motivated by the presence of a significant share of the latter in the domestic CPI basket. Last but not least, the external dimension of the model was modified by modeling the rest of the foreign sector as a two country (Euro area and US/Rest of the world) open economies new Keynesian semi-structural model, given the currency structure of the Romanian foreign trade in goods and services. As the foreign currency financial transactions take place only in EUR, the channels through which external shocks affect the domestic economy differ according to the originating country.

When taking the model to the data, a number of issues deserved to be mentioned. First, to reconcile the specific growth rates of the observed variables with the balanced growth path of the model, the approach of Argov et al. (2012) was used for model consistent filtering. Moreover, the real GDP and the corresponding deflator were defined in a manner consistent with the National Accounts measures.

We estimated the model using 29 observable variables and the endogenous priors procedure as proposed by Christiano et al. (2011), modified to allow matching certain moments only for a subset of variables. Given data availability and the need for a time-invariant policy rule sample (i.e. inflation targeting), the time span covered is 2005Q3:2014Q3.

While displaying theoretically valid reactions of the endogenous variables to the structural shocks, impulse response functions revealed the importance of the currency substitution, balance sheet and wealth effects, captured when modeling two distinct types of entrepreneurs (defined with respect to the currency they borrow in). Accordingly, the currency denomination of foreign financial flows (EUR in our case) and the degree of euroization (the relative shares of the two types of entrepreneurs) matter for the reaction of sector specific and aggregate endogenous variables.

Furthermore, given the excess trends specification we use, the model perfectly matched observed variables' means. Applying the endogenous priors procedure resulted in efficiently matching standard deviations as well, despite a rich theoretical structure, short sample length, and high sampling uncertainty for some variables.

Variance decomposition analysis revealed the high contributions of financial sector (risk premium included) and export related shocks, pointing towards the importance of both financial frictions and open economy dimensions. At the same time, the effects of labor market frictions appeared to be rather limited. Some unobserved variables retrieved by the Kalman smoother captured fairly well the developments in their data counterparts, like bankruptcy rates, vacant jobs or the risk premium. Moreover, historical decomposition analysis offered relevant insights with respect to the importance of particular shocks. Demand side shocks appeared as important sources of output and private consumption dynamics, while financial sector (risk premium included) related shocks explain much of the fluctuations in investment, interest rate spreads and exchange rate.

Regarding the in-sample forecasting performance, the DSGE model usually performs better than a random walk and similar to univariate models, but is generally worse than the Bayesian VAR models.

The estimated model allowed also simulating and evaluating some complex scenarios, like simultaneous monetary policy shocks of opposite signs in the two foreign economies for different levels of euroization of the domestic economy. While a shock originating in the US economy directly influences domestic variables via the net exports channel, a shock to the Euro area economy has an additional direct impact through the balance sheet channel, given EUR denomination of foreign currency loans. Moreover, the importance of the latter mentioned mechanism depends positively on the euroization degree of the domestic economy. Therefore, the increase in investment following the decrease in the EURIBOR interest rate leads to a stronger increase in output when euroization is higher. If the foreign currency loans had been denominated in USD, the increase in the US interest rate would have led to a stronger decline in output in the more dollarized economy.

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6 Appendix

6.1 Estimated external sector

As mentioned throughout the paper and described in details in section 2.8, the estimation of the external sector is performed outside the main model. Given this latter aspect, the semi-structural nature of the external sector model and, implicitly, the relatively high number of coefficients to be estimated, we chose to work with data that covers a longer time span than that used for the Romanian economy, taking also into account its availability for the US and Eurozone economies. The series used in estimation cover the 1995Q2-2014Q3 period and are presented in table 12 and plotted in figure 24 below.

When feeding data into the external sector model, we take into account that in the data foreign variables have different growth rates than the domestic model-implied ones. Therefore, we extend the specific trends approach to these variables also. The measurement equations used are the ones presented in section 3.2 of the paper.

Estimated parameters and standard deviations of the shocks are presented in tables 13 and 14 below.

Similar with the main model, we use the endogenous priors procedure as proposed by Christiano et al. (2011) when estimating the external sector model. Table 11 presents the means and the standard deviations in the data as well as those generated by the model. While the specific trends approach helps us in matching the means of the used data series (excepting the output gaps, for which the excess trend components are not specified), the endogenous priors approach does an excellent job in matching the variability in the series, as measured by their standard deviations (including oil prices, for which a high sampling uncertainty is encountered).

Table 11: *External sector: data and model moments (in percent)*

External sector: 1995Q2-2014Q3						
Variable	Explanation	Means		St. dev.		Sampling
		Data	Model	Data	Model	uncertainty
Euro area						
$100{*}y^{EUR,gap}$	GDP gap	-0.2	0	1.8	1.5	0.6
$400{*}\pi^{EUR}$	Inflation	1.9	1.9	1.2	1.2	0.3
$400{*}(R^{EUR}-1)$	Interest rate	2.9	2.9	1.8	1.5	0.6
United States						
$100{*}y^{US,gap}$	GDP gap	-0.2	0	1.4	1.3	0.5
$400{*}\pi^{US}$	Inflation	2.3	2.3	2.0	2.1	2.0
$400{*}(R^{US}-1)$	Interest rate	2.9	2.9	2.3	2.0	0.6
$100{*}s^{USD/UER}$	USD/EUR exchange rate	0.1	0.1	4.1	3.9	2.6
$400{*}\pi^{oil,USD}$	Oil inflation	8.9	8.9	53.9	49.0	1021.9

Table 12: *Series used in the estimation of the external sector: 1995Q2-2014Q3*

	Description	*Details*	*Source of primary data*
π_t^{EUR}	Euro area inflation rate	HICP inflation, quarterly rate	ECB
π_t^{US}	US inflation rate	CPI, quarterly rate	FRED
R_t^{EUR}	Euro area interest rate	Euribor, 3 months market rate	Eurostat
R_t^{US}	US interest rate	Federal funds rate	FRED
π_t^{EUR}	Euro area inflation rate	HICP inflation, quarterly rate	ECB
Logged first difference			
$\Delta S_t^{USD/EUR}$	Nominal USD/EUR exchange rate	Nominal USD/EUR exchange rate	NBR
$\Delta Poil_t^{USD}$	Change in oil prices	Brent Oil price, USD/barrel	EIA
Filtered log level (output gaps)			
$y_t^{EUR,gap}$	Euro area GDP gap	Interpolated from annual data	EC
$y_t^{US,gap}$	US GDP gap	Interpolated from annual data	EC

Figure 24: *Observed data series and estimated model consistent trends: external sector*

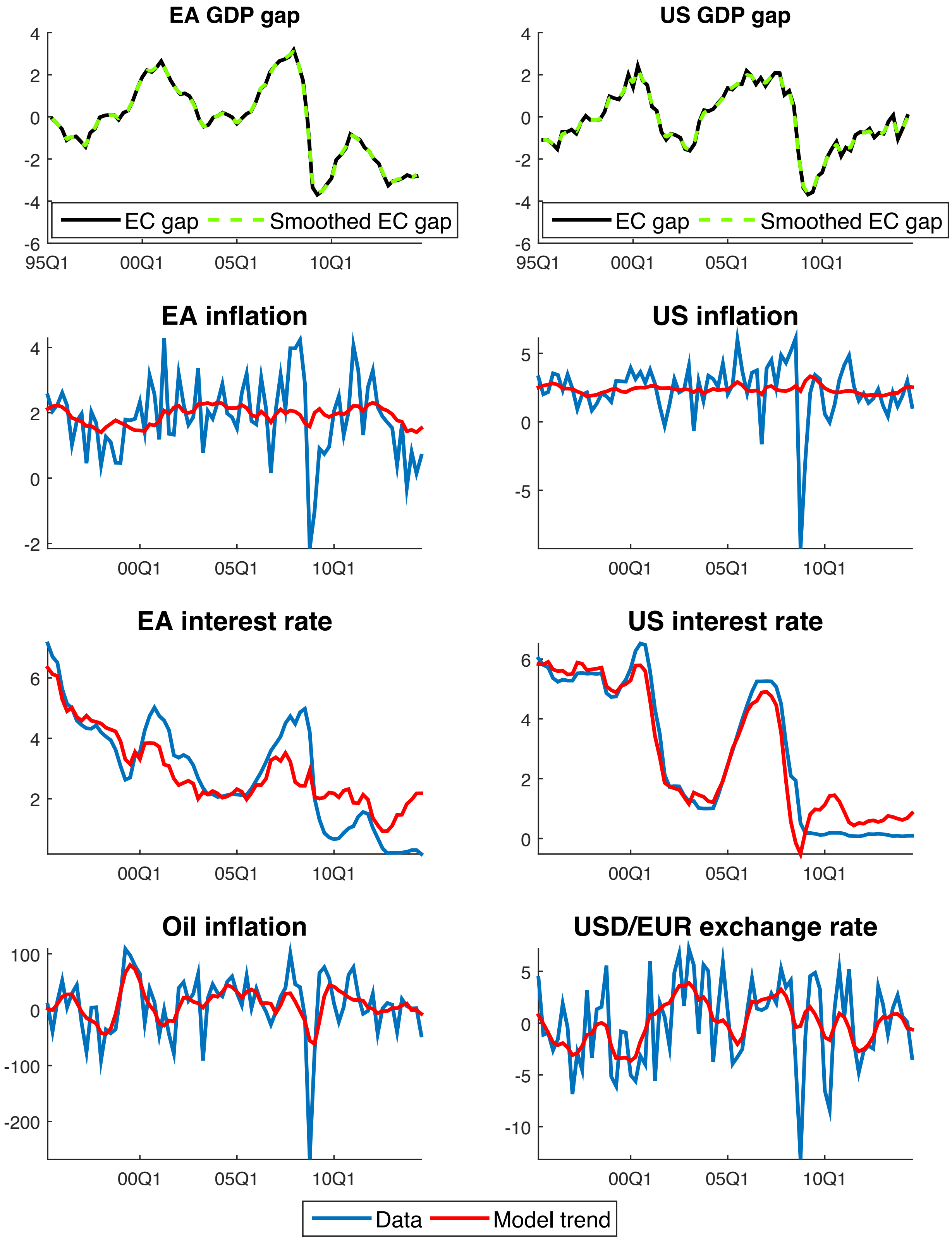

Table 13: *Estimated parameters: external sector*

Based on single Metropolis chain with 400,000 draws, after a burn in period of 200,000 draws.

Parameter	Prior			Posterior	
	Distr.	Mean	s.d./dof	Mean	s.d.
Euro area aggregate demand curve					
$is_{eur,bl}$	β	0.4	0.05	0.504	0.025
$is_{eur,r}$	Γ	0.1	0.025	0.095	0.024
$is_{eur,q}$	Γ	0.05	0.01	0.020	0.004
$is_{eur,f}$	Γ	0.025	0.01	0.078	0.012
$100\sigma_{y^{EUR}}$	Inv-Γ	0.25	2	0.262	0.036
Euro area Phillips curve					
$pc_{eur,bl}$	β	0.3	0.1	0.052	0.020
$pc_{eur,mc}$	Γ	0.1	0.015	0.047	0.006
$pc_{eur,q}$	Γ	0.025	0.015	0.012	0.005
$pc_{eur,oil1}$	Γ	0.005	0.001	0.004	0.001
$pc_{eur,oil2}$	Γ	0.005	0.001	0.003	0.001
$100\sigma_{\pi^{EUR}}$	Inv-Γ	0.25	2	0.143	0.017
Euro area Taylor rule					
$tr_{eur,bl}$	β	0.7	0.01	0.845	0.024
$tr_{eur,y}$	Γ	0.125	0.05	0.127	0.035
$tr_{eur,\pi}$	Γ	1.7	0.15	1.690	0.148
$1000\sigma_{R^{EUR}}$	Inv-Γ	1.5	2	0.485	0.100
US aggregate demand curve					
$is_{us,bl}$	β	0.4	0.05	0.432	0.030
$is_{us,r}$	Γ	0.1	0.025	0.120	0.027
$is_{us,q}$	Γ	0.025	0.01	0.016	0.004
$is_{us,f}$	Γ	0.01	0.005	0.009	0.004
$100\sigma_{y^{USD}}$	Inv-Γ	0.25	2	0.215	0.040
US Phillips curve					
$pc_{us,bl}$	β	0.3	0.1	0.072	0.026
$pc_{us,mc}$	Γ	0.1	0.015	0.078	0.011
$pc_{us,q}$	Γ	0.05	0.015	0.054	0.012
$pc_{us,oil1}$	Γ	0.005	0.001	0.006	0.001
$pc_{us,oil2}$	Γ	0.005	0.001	0.004	0.001
$100\sigma_{\pi^{USD}}$	Inv-Γ	0.5	2	0.322	0.036
US Taylor rule					
$tr_{us,bl}$	β	0.7	0.1	0.912	0.018
$tr_{us,y}$	Γ	0.125	0.05	0.166	0.053
$tr_{us,\pi}$	Γ	1.5	0.15	1.432	0.143
$1000\sigma_{R^{USD}}$	Inv-Γ	2.5	2	0.666	0.116
Uncovered interest parity condition					
uip^{*}	β	0.65	0.1	0.427	0.038
$100\sigma_{uip^{*}}$	Inv-Γ	1	2	1.944	0.133
Price of oil in USD					
$ar_{1,oil}$	β	0.7	0.15	0.313	0.075
$ar_{2,oil}$	N	0	0.1	0.335	0.078
$10\sigma_{oilusd}$	Inv-Γ	0.5	2	0.821	0.077

Table 14: *Estimated parameters: external sector, excess trends*

Based on single Metropolis chain with 400,000 draws, after a burn in period of 200,000 draws.					
Parameter	Prior			Posterior	
	Distr.	Mean	s.d./dof	Mean	s.d.
Excess trends AR coefficients					
$\rho^{R^{EUR},EXT}$	β	0.8	0.05	0.889	0.026
$\rho^{R^{US},EXT}$	β	0.8	0.05	0.928	0.011
$\rho^{\pi^{EUR},EXT}$	β	0.8	0.05	0.754	0.049
$\rho^{\pi^{US},EXT}$	β	0.8	0.05	0.758	0.052
$\rho^{S^{USD/EUR},EXT}$	β	0.5	0.15	0.725	0.063
$\rho^{\pi^{oil,USD},EXT}$	β	0.5	0.15	0.741	0.079
Standard deviations					
$\sigma_{R^{EUR},EXT}$	Inv-Γ	$\sqrt{0.3}$	10	0.533	0.014
$\sigma_{R^{US},EXT}$	Inv-Γ	$\sqrt{0.54}$	10	0.719	0.019
$\sigma_{\pi^{EUR},EXT}$	Inv-Γ	$\sqrt{0.13}$	10	0.285	0.044
$\sigma_{\pi^{US},EXT}$	Inv-Γ	$\sqrt{0.42}$	10	0.513	0.085
$\sigma_{S^{USD/EUR},EXT}$	Inv-Γ	$\sqrt{1.7}$	10	1.321	0.038
$\sigma_{\pi^{oil,USD},EXT}$	Inv-Γ	$\sqrt{295}$	10	17.661	0.523
$\sigma_{y^{EUR},ME}$	Inv-Γ	$\sqrt{0.04}$	10	0.165	0.029
$\sigma_{y^{US},ME}$	Inv-Γ	$\sqrt{0.04}$	10	0.194	0.039

6.2 Estimated parameters - excess trends

Table 15: *Estimated auto-regressive parameters and st. deviations - excess trends*

Based on single Metropolis chain with 400,000 draws, after a burn in period of 200,000 draws.

Parameter	Prior			Posterior			
	Distr.	Mean	s.d.	Mean	s.d.	10%	90%
$\rho^{\bar{\pi}^c,EXT}$	β	0.1	0.025	0.104	0.026	0.060	0.144
$\rho^{\pi^{GDP},EXT}$	β	0.15	0.05	0.103	0.035	0.046	0.159
$\rho^{\pi^c,EXT}$	β	0.15	0.05	0.112	0.037	0.050	0.169
$\rho^{\pi^{core1},EXT}$	β	0.15	0.05	0.112	0.037	0.052	0.169
$\rho^{\pi^i,EXT}$	β	0.15	0.05	0.106	0.037	0.045	0.164
$\rho^{\pi^x,EXT}$	β	0.15	0.05	0.130	0.043	0.059	0.197
$\rho^{\pi^m,EXT}$	β	0.15	0.05	0.136	0.045	0.063	0.208
$\rho^{c,EXT}$	β	0.15	0.05	0.142	0.048	0.066	0.221
$\rho^{i,EXT}$	β	0.15	0.05	0.160	0.052	0.074	0.241
$\rho^{x,EXT}$	β	0.15	0.05	0.173	0.056	0.081	0.263
$\rho^{m,EXT}$	β	0.15	0.05	0.131	0.043	0.062	0.198
Parameter	Prior			Posterior			
	Distr.	Mean	df.	Mean	s.d.	10%	90%
$\sigma_{\bar{\pi}^c,EXT}$	Inv-Γ	0.35	100	0.338	0.023	0.299	0.375
$\sigma_{\pi^{GDP},EXT}$	Inv-Γ	2.25	100	4.197	0.254	3.784	4.624
$\sigma_{\pi^c,EXT}$	Inv-Γ	0.96	100	0.797	0.036	0.740	0.856
$\sigma_{\pi^{core1},EXT}$	Inv-Γ	1.05	100	0.803	0.034	0.750	0.860
$\sigma_{\pi^{adm},EXT}$	Inv-Γ	1.55	100	1.533	0.087	1.393	1.675
$\sigma_{\pi^i,EXT}$	Inv-Γ	5.78	100	13.40	1.026	11.66	15.04
$\sigma_{\pi^x,EXT}$	Inv-Γ	4.56	100	5.488	0.425	4.769	6.171
$\sigma_{\pi^m,EXT}$	Inv-Γ	4.29	100	4.652	0.370	4.044	5.255
$\sigma_{\Delta y,ME}$	Inv-Γ	0.36	100	0.440	0.041	0.374	0.506
$\sigma_{\Delta c,EXT}$	Inv-Γ	0.68	100	0.716	0.056	0.625	0.806
$\sigma_{\Delta i,EXT}$	Inv-Γ	2.45	100	2.831	0.218	2.472	3.184
$\sigma_{\Delta x,EXT}$	Inv-Γ	1.90	100	1.651	0.148	1.410	1.890
$\sigma_{\Delta m,EXT}$	Inv-Γ	1.38	100	1.928	0.146	1.689	2.164
$\sigma_{\Delta ft,ME}$	Inv-Γ	4.36	100	4.694	1.185	2.870	6.469
$\sigma_{\Delta spread^{DC}}$	Inv-Γ	5.62	100	7.602	0.590	6.635	8.585
$\sigma_{\Delta spread^{FC}}$	Inv-Γ	2.65	100	3.001	0.276	2.541	3.440
$\sigma_{\Delta s^{RON/EUR}}$	Inv-Γ	1.00	100	1.295	0.103	1.128	1.469
$\sigma_{\Delta H}$	Inv-Γ	0.35	100	0.344	0.024	0.306	0.382
$\sigma_{\Delta U}$	Inv-Γ	1.31	100	1.608	0.138	1.376	1.828
$\sigma_{\Delta W}$	Inv-Γ	0.62	100	0.969	0.078	0.841	1.091

6.3 Impulse response functions

Figure 25: *IRFs to the unit root neutral technology shock*

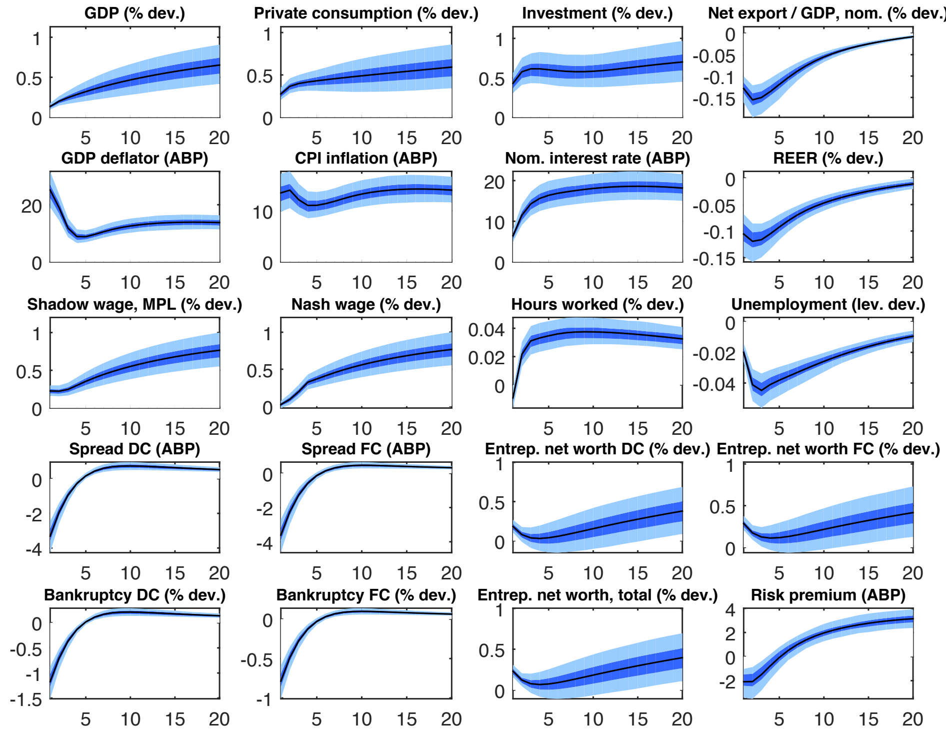

Figure 26: *IRFs to the marginal efficiency of investment shock*

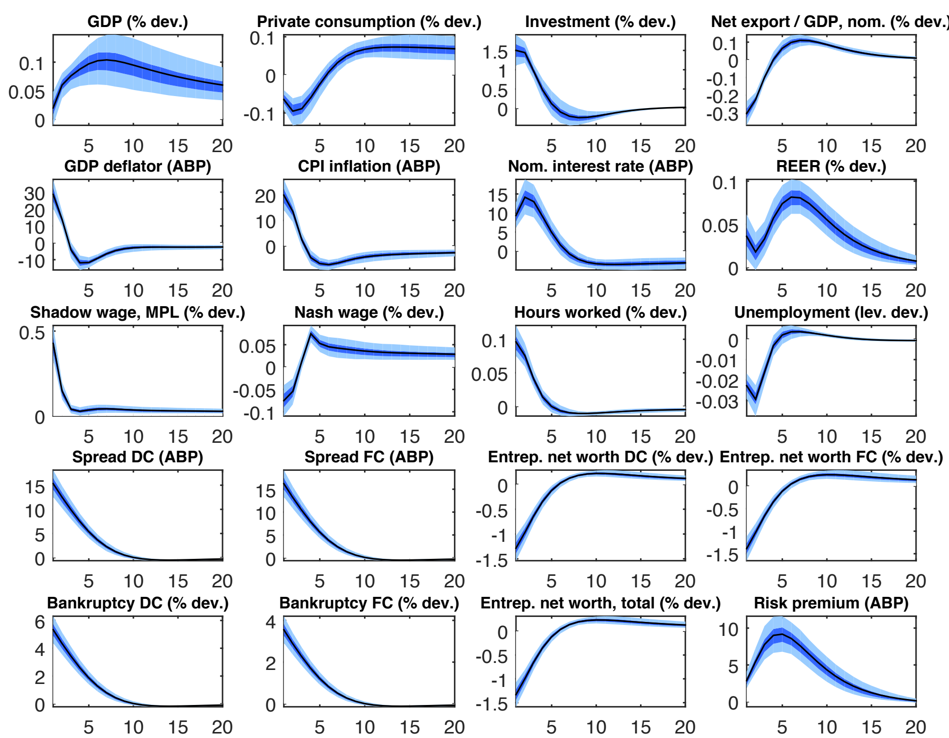

Figure 27: *IRFs to the labor disutility shock*

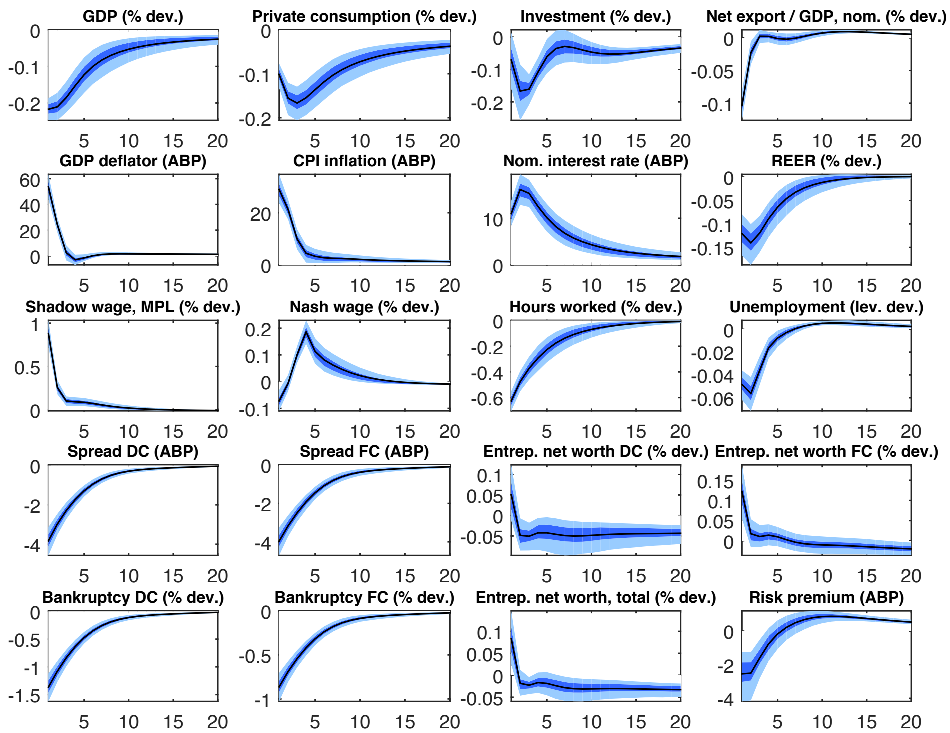

Figure 28: *IRFs to the government expenditure shock*

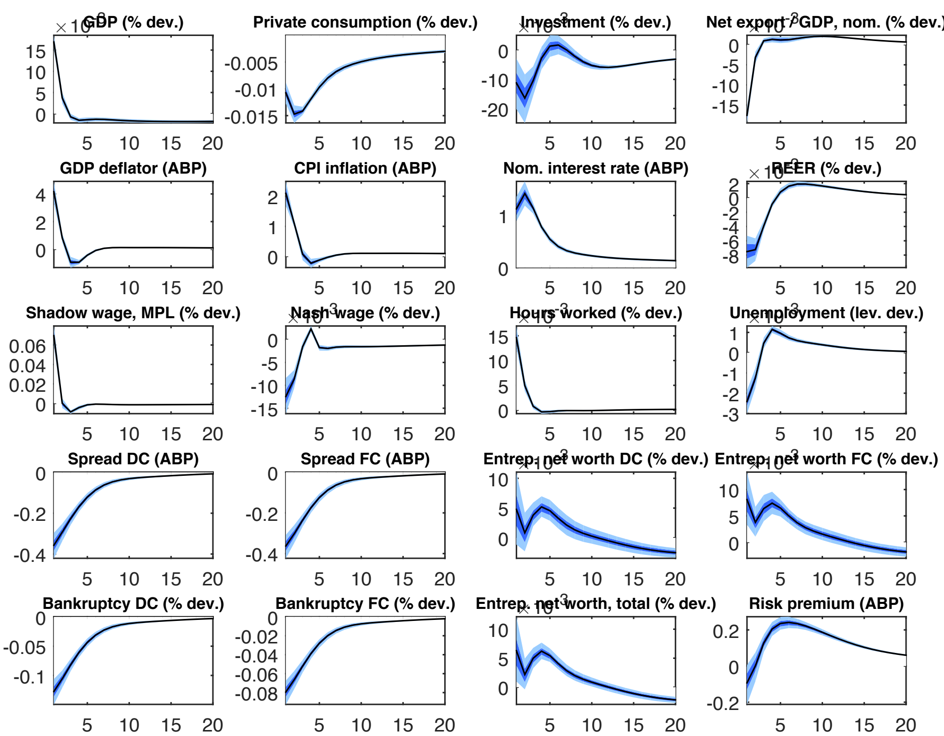

Figure 29: *IRFs to the exports markup shock*

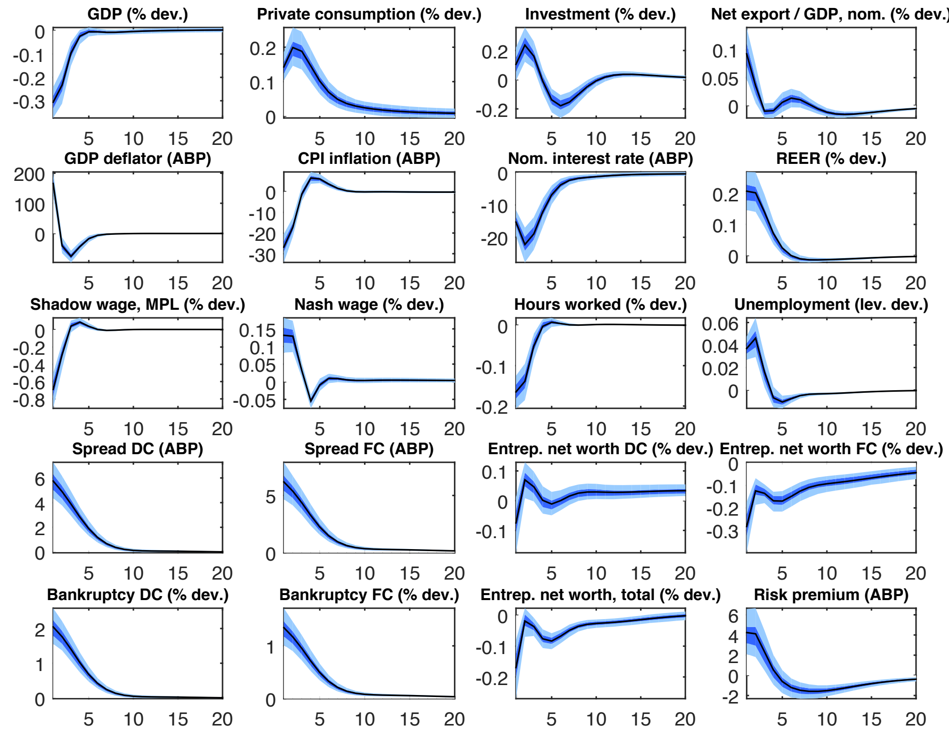

Figure 30: *IRFs to the imported consumption markup shock*

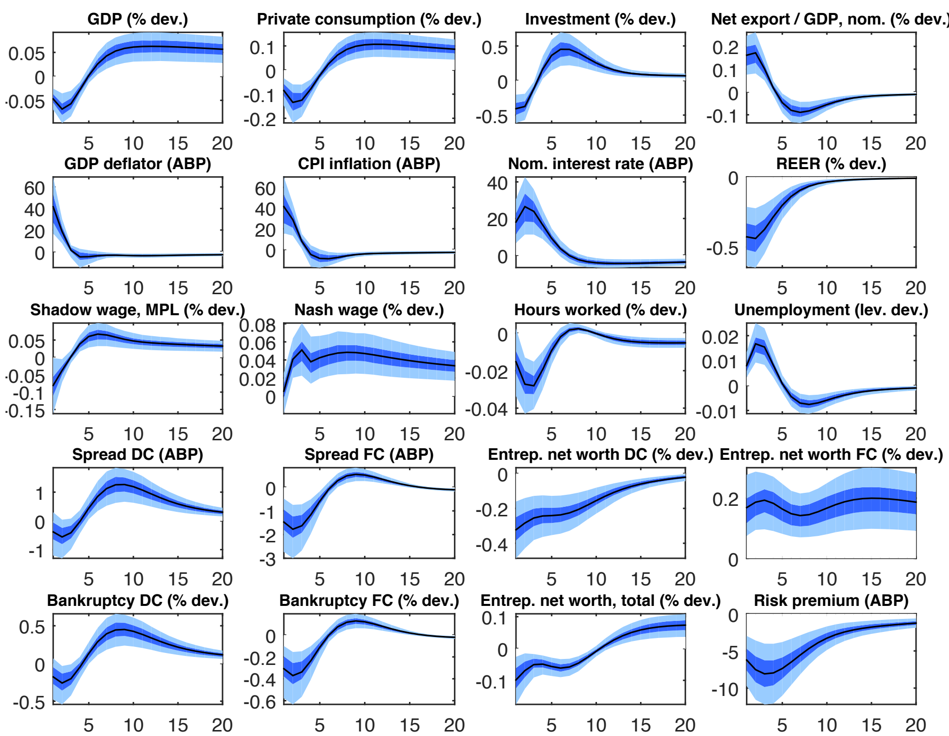

Figure 31: *IRFs to the imported investment markup shock*

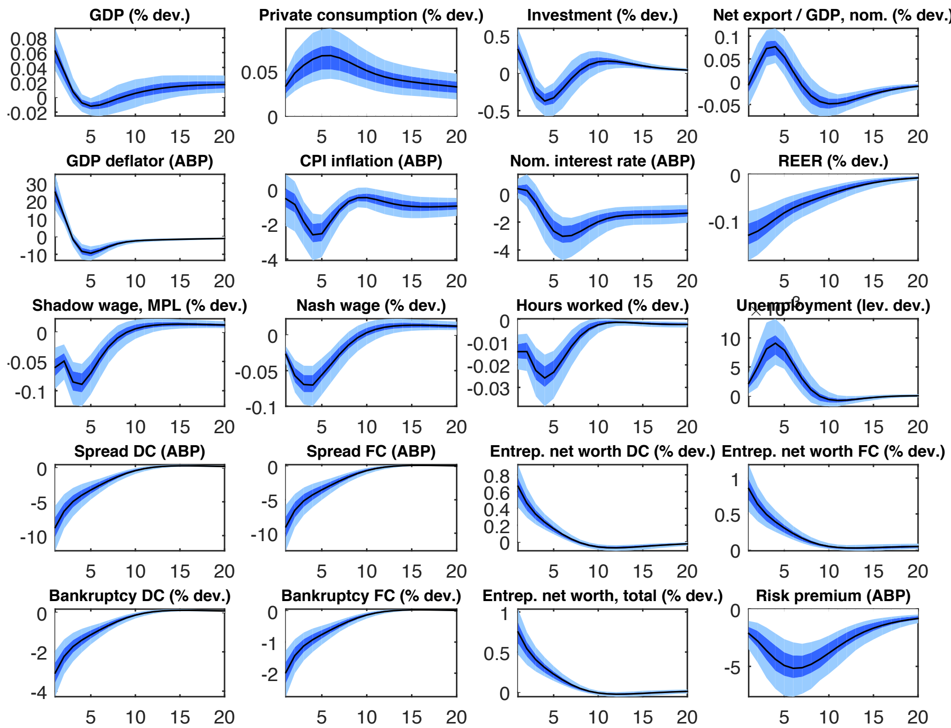

Figure 32: *IRFs to the imported exports markup shock*

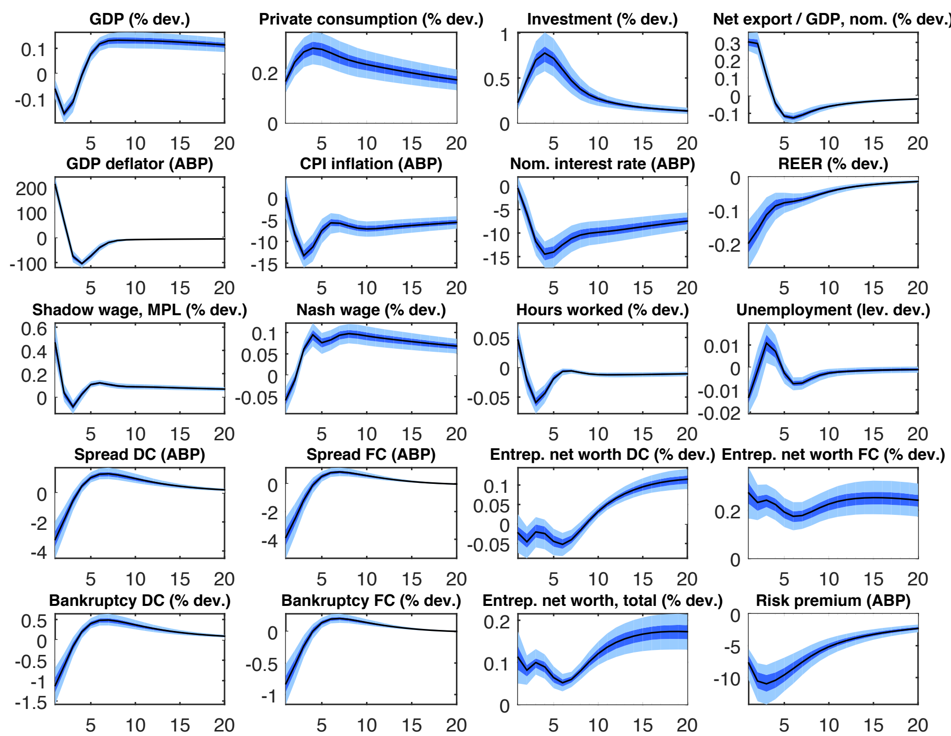

Figure 33: *IRFs to the imported oil markup shock*

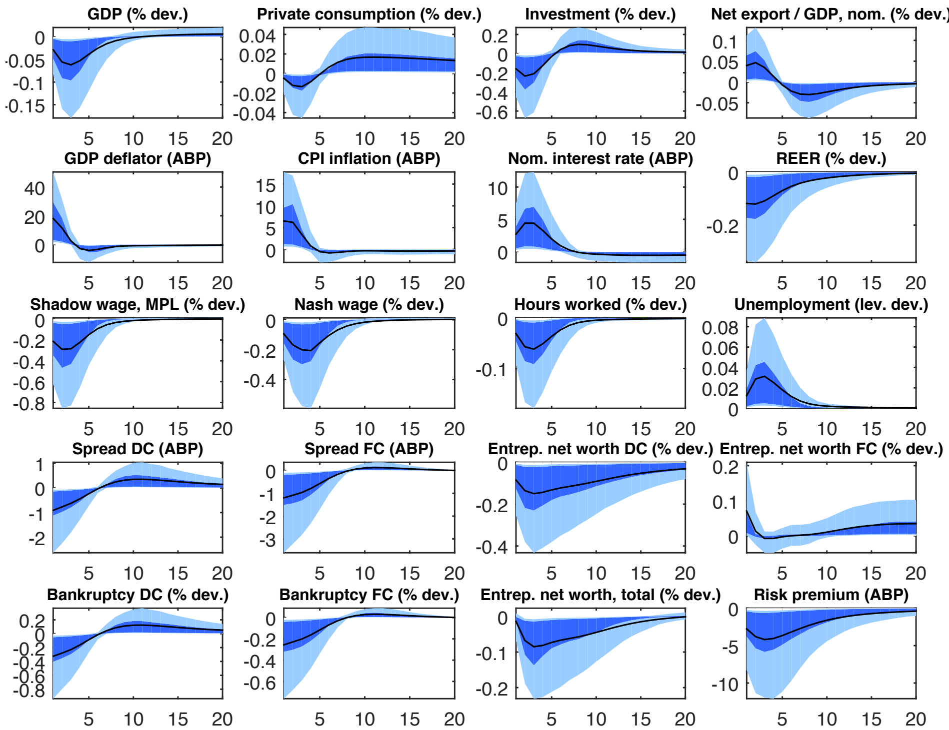

Figure 34: *IRFs to the entrep. net worth shock, FC*

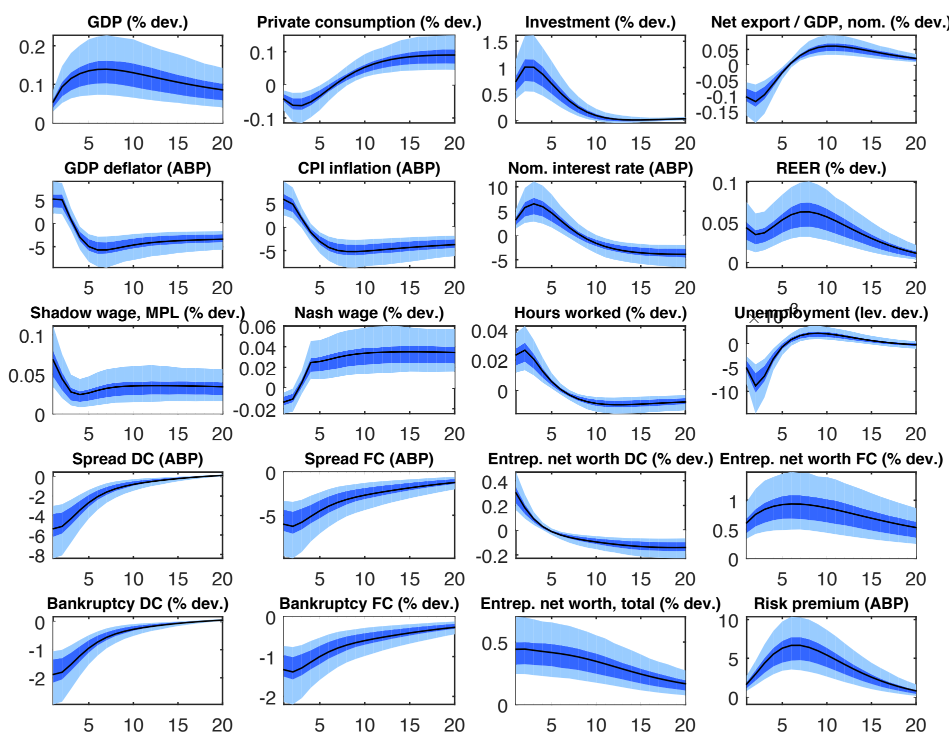

Figure 35: *IRFs to the Euro area GDP shock*

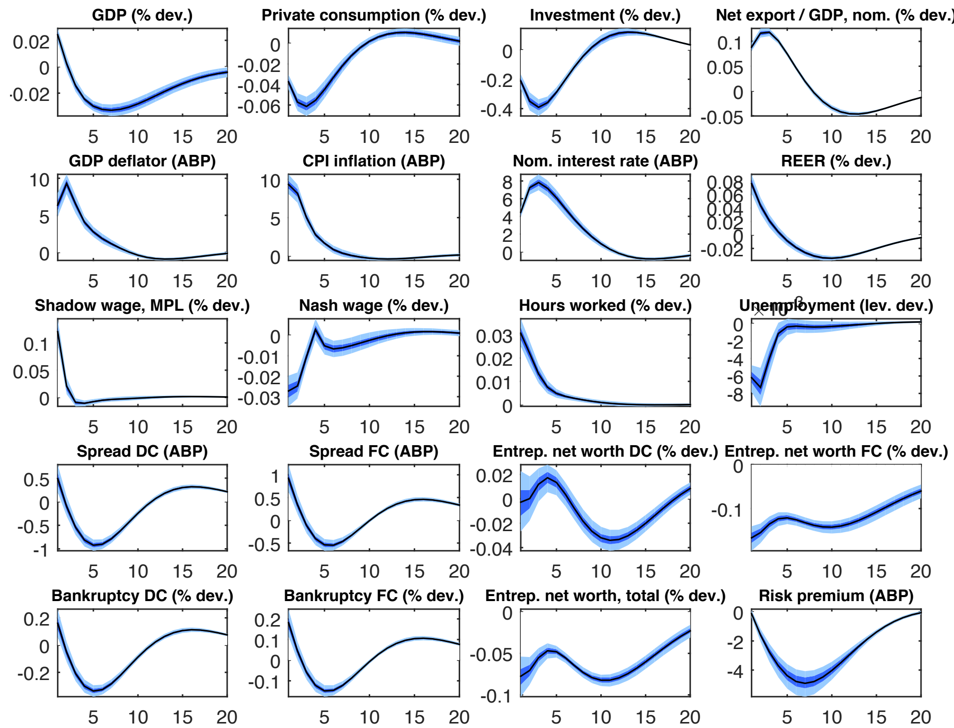

Figure 36: *IRFs to the US GDP shock*

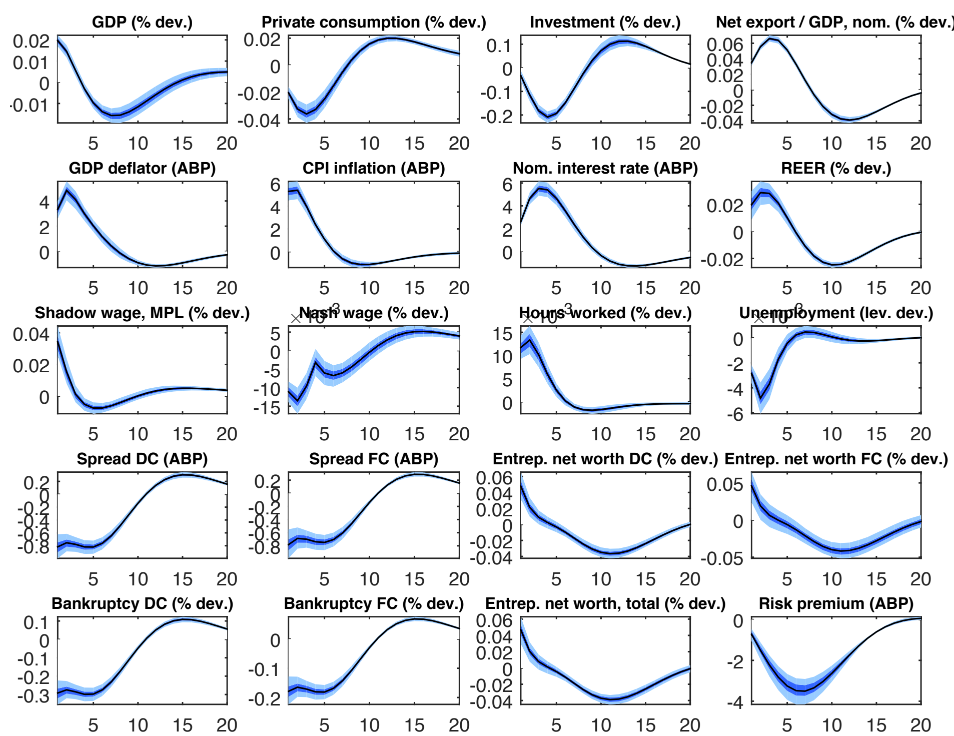

Figure 37: *IRFs to the Euro area inflation shock*

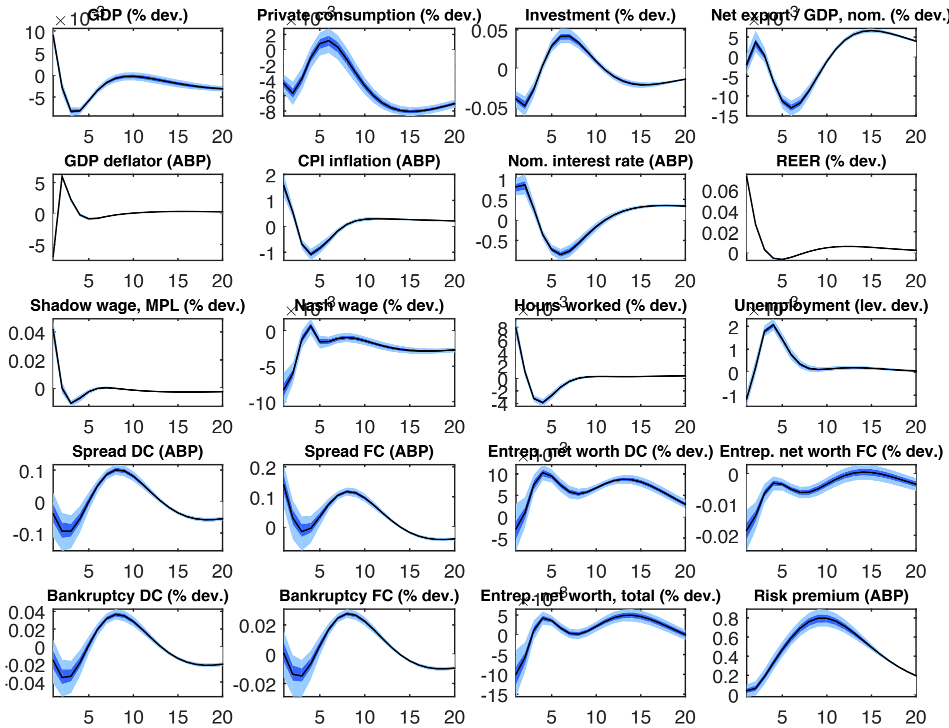

Figure 38: *IRFs to the US inflation shock*

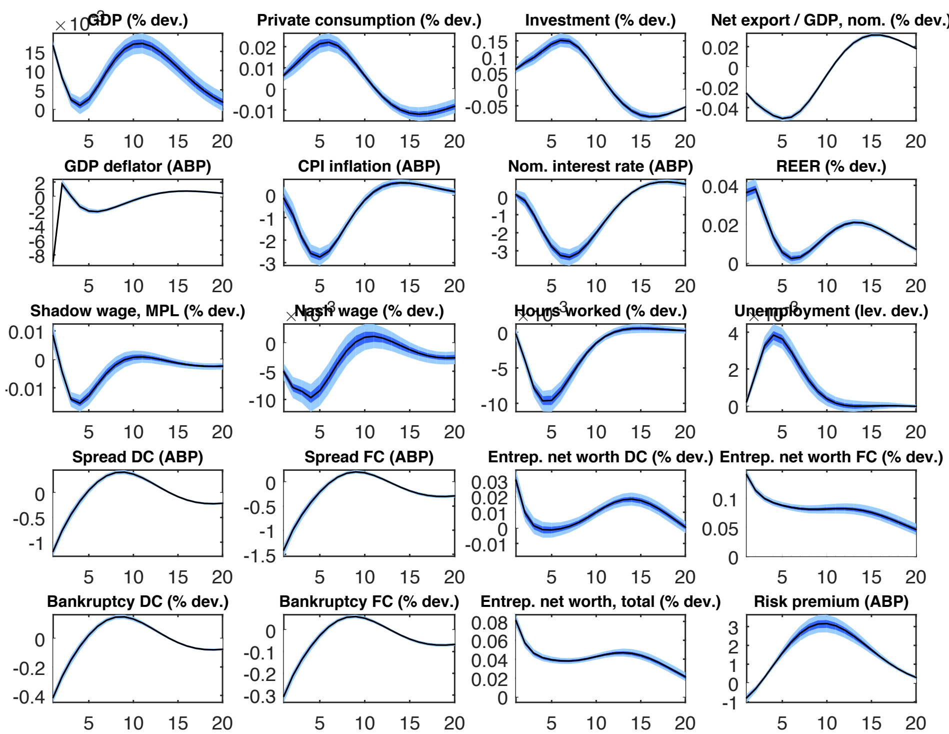

Figure 39: *IRFs to the Euro area monetary policy shock*

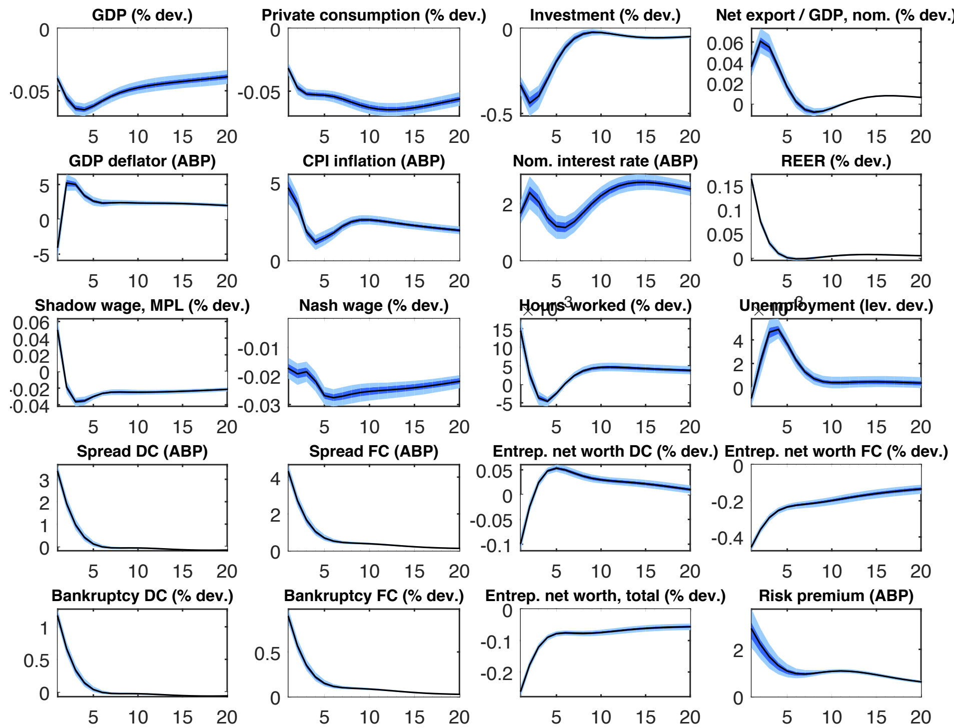

Figure 40: *IRFs to the US monetary policy shock*

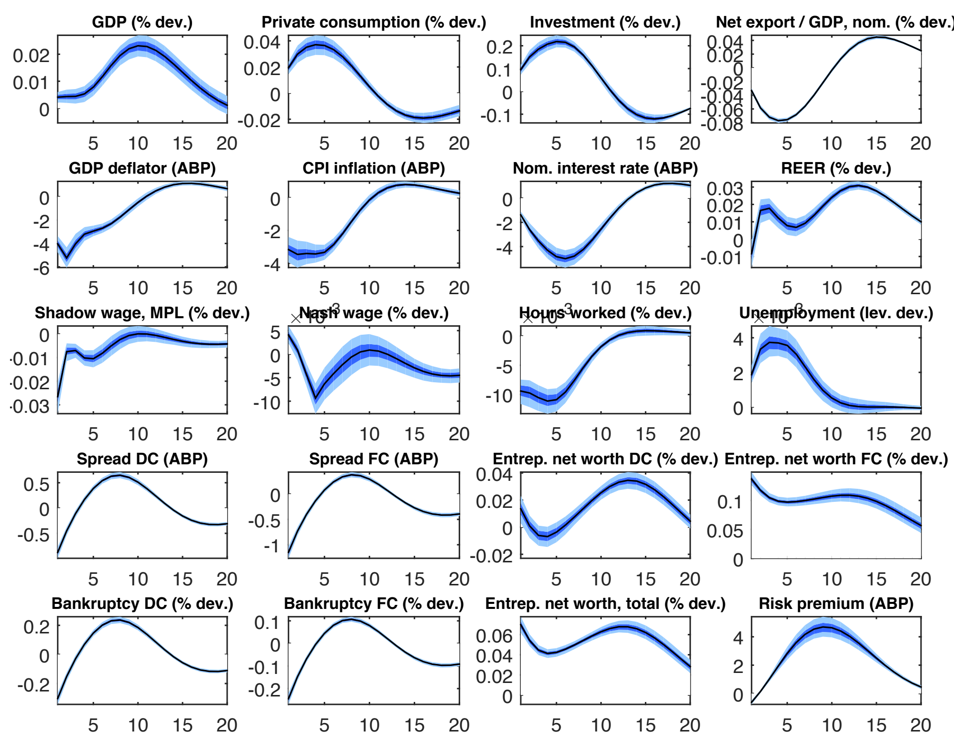

Figure 41: *IRFs to the EUR/USD UIP shock*

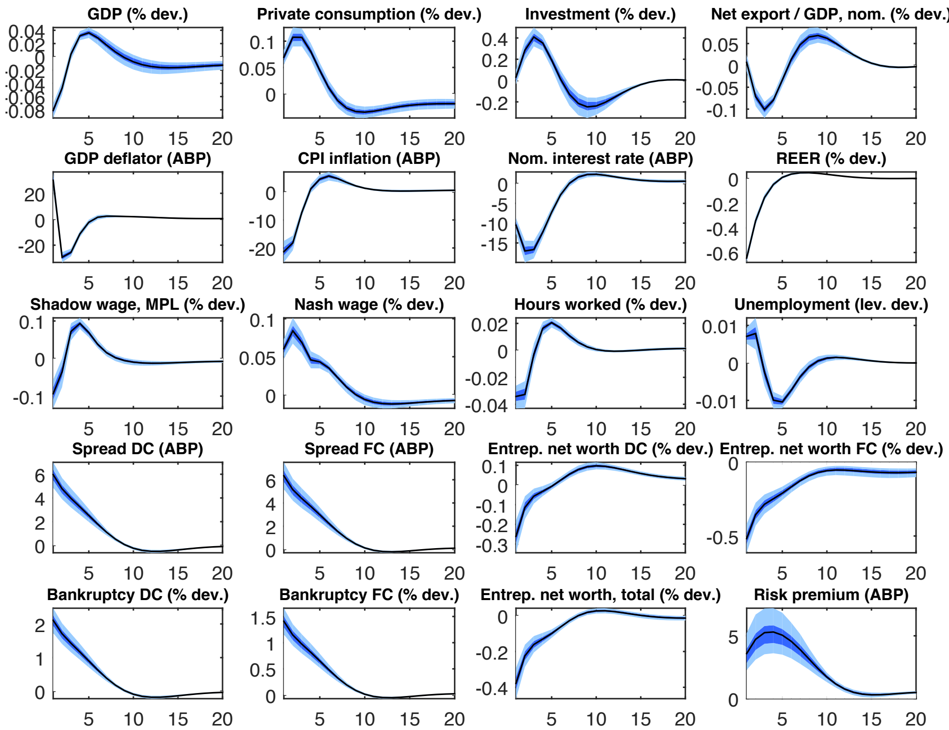

Figure 42: *IRFs to the oil price shock*

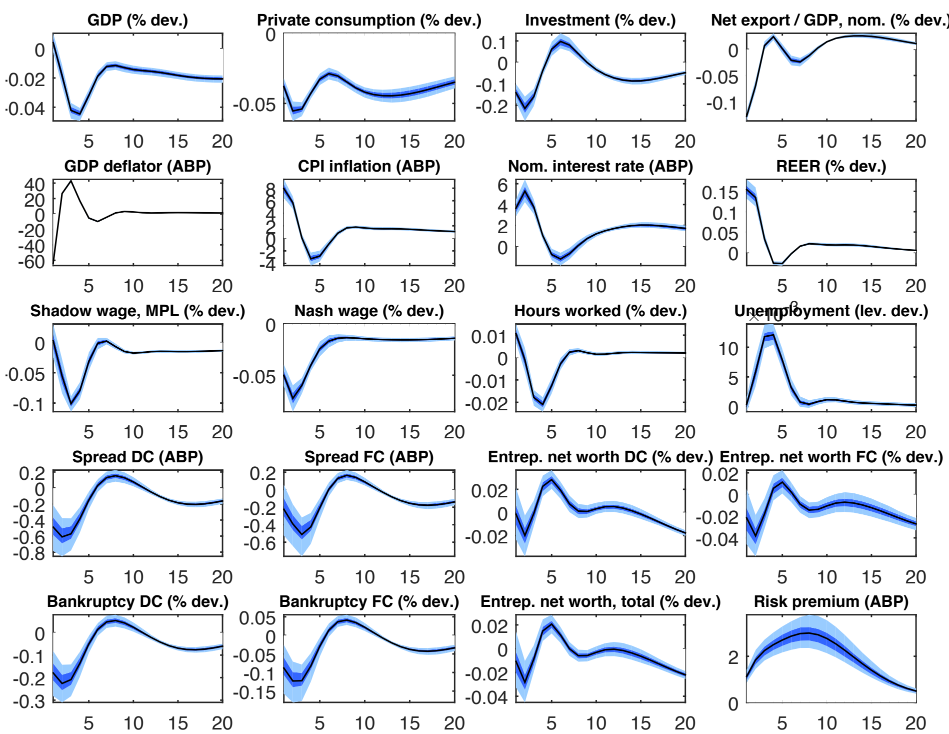

Figure 43: *IRFs to the administered prices shock*