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The EAGLE model for Hungary–a global perspective *

(Az EAGLE model Magyarországra globális perspektívában)

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Abstract

In this paper we adopt the Hungarian version of the EAGLE (**E**uro **A**rea **GL**obal **E**conomy) model. The version of the EAGLE model used in this paper allows for the high import content of export–a typical feature of small open economies such as Hungary. We study the effects of four globally important shocks on Hungary: i) a slowdown of the Chinese economy, ii) more restrictive US monetary policy, iii) a reduction in oil prices, and iv) more protectionist US trade policy. We found these policies to have non-negligible indirect effects (beyond the relatively small direct ones) on Hungary mostly due to the workings of the shock to the eurozone which is our main trade partner.

JEL: E12, E13, E52, E58, F11, F41.

Keywords: multi-country DSGE, price and wage rigidity, EAGLE model, trade matrix, import content of export, local currency pricing, monetary policy shock, consumption preference shock, markup-shock.

Összefoglaló

A papír az EAGLE (**E**uro **A**rea **GL**obal **E**conomy) modell Magyarországra adaptált verzióját mutatja be. Magyarország mint kis-nyitott gazdaság egyik specifikuma, hogy az exportnak magas az importtartalma, amelyet a modell figyelembe vesz. Négy globálisan is jelentős sokk Magyarországra vonatkozó másodkörös hatását számszerűsítjük: i) a kínai gazdaság lassulása, ii) az USA várhatóan szigorúbb monetáris politikája, iii) az olajárak csökkenése és iv) az USA protekcionistább kereskedelmi politikája. Azt találjuk, hogy ezeknek a sokkoknak az indirekt (másodkörös) hatásai nem elhanyagolhatóak (a relatíve kisebb direkt hatások mellett) és elsősorban Magyarország legnagyobb kereskedelmi partnerétől, az eurozónából gyűrűznek be.

1 Introduction

The current macroeconomic and forecasting model of the Central Bank of Hungary focuses on the precise description of the Hungarian economy such as the distinction between borrower (indebted) and saver households and abstracts from a detailed characterization of the foreign sector. But an ample description of the trade connections of Hungary with foreign countries can provide better understanding of the effects and spillovers of global shocks.

The EAGLE model is developed by Gomes et al. (2012) under the auspices of the Working Group on Econometric Modeling (WGEM) at the European Central Bank building on the New Area Wide Model (NAWM). The EAGLE model differs from NAWM in at least three aspects.

The baseline EAGLE model contains four regions of which two are members of the European Monetary Union creating the opportunity to model the relationship of the monetary union with countries outside the union. A major achievement of the EAGLE is the global perspective: beyond the monetary union there two more blocks representing the United States and the rest of the world (mainly developing countries including China). With the global perspective it is therefore possible to model either demand (e.g. food price shock due to bad harvest) or supply (oil price shock due to lower supply) shocks coming from either US or the rest of the world. The trade connections in the EAGLE and the New Monetary Policy Model are compared on Figures 2 and 3. The third important new feature of the EAGLE model is inclusion of international relative prices and exchange rates and the associated trade flows.

In this paper we study a version of the EAGLE model which excludes the monetary union as Hungary (the smallest of the four regions see Figure 1) is not part of the monetary union. The other three regions are the eurozone, the United States and the rest of world (including developing countries). The EAGLE model makes it possible to study the role of country characteristics such as the size and direction of trade with other countries, fiscal and monetary policies, labour market differences and other production-specific factors in the transmission of country-specific and/or global shocks using common framework.

An important element of the EAGLE model calibrated for Hungary is the high import content of export. Studying the last 20 years of Hungarian OECD trade data we find that the import content of export is about 55 per cent. To match the high import content of export we modify the baseline EAGLE in a way that we introduce a new good the so-called export good that is made of domestically produced and imported intermediary goods by monopolistically competitive firms and which is priced in the currency of the target country (local currency pricing assumption, see Coenen and Vetlov (2009)).

The four blocks (Hungary, the eurozone, US, and the rest of the world) have symmetric model structure (about 250 equations per block) the diverse behaviour of each region to global shocks can be traced back to the different calibration of each block. For model calibration we have to find the right value for more than 300 parameters. To help calibrate the model the ECB developed a tool (EAGLE Calibration Help Tool) but the calibration of the Hungarian region relies for some of the parameters on expert advice from the MNB staff. By the end of 2016 most eurozone and non-eurozone countries developed their own version of the EAGLE model.

Several applications of the EAGLE are published, here we mention a few of them. Clancy et al. (2016) study fiscal devaluation (a decrease in labour taxes is ex-ante neutralized with a rise in consumption taxes) in a small open economy. Lejeune (2016) studies a large fiscal devaluation in case of Belgium. Brozoza-Brezina et al. (2014) study what kind of policy help to smooth the volatility of the Polish economy in the accession process to the eurozone. Gomes et al. (2014) use the EAGLE framework to determine what kind of stabilization policy can be optimal globally after interest rates in one or many blocks have hit its zero lower bound.

Figure 1
Comparing the size of the blocks in the EAGLE model

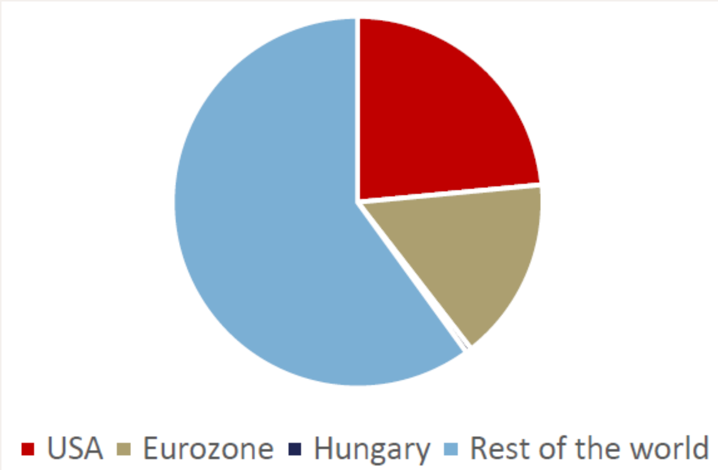


Figure 2
Trade connections of Hungary in the EAGLE model

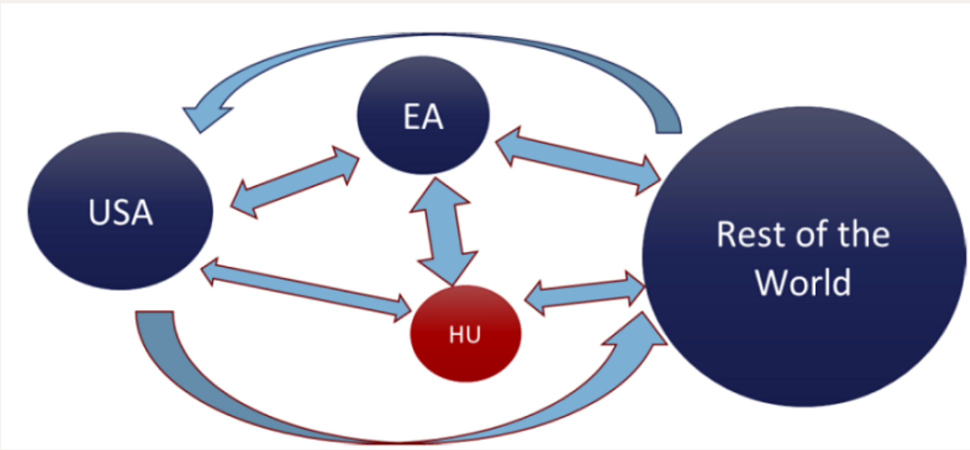
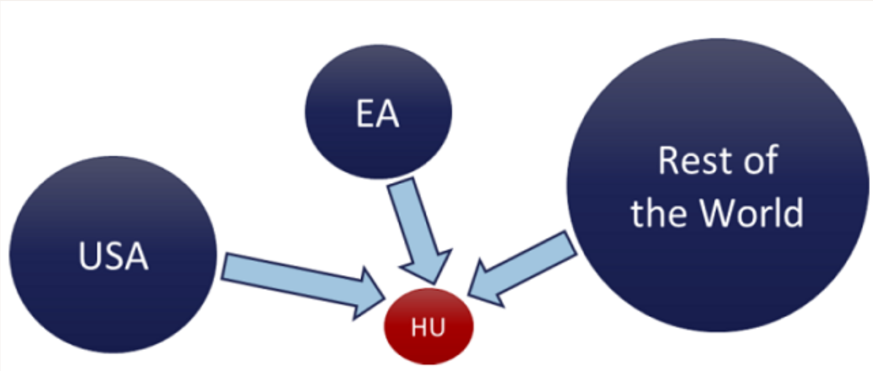


Figure 3
Trade connections of Hungary in the New Monetary Policy Model (NPM).



2 Overview of the structure of the EAGLE model

2.1 FIRMS

There are two types of firms in the EAGLE model: intermediaries and final good firms. Intermediaries produce tradable and non-tradable products while final good firms bundle final consumption and investment good from traded and non-traded goods and the final export good. It is a distinctive feature of the Hungarian model that that *the import of export good* from other countries is used in the production of the final export good. The structure of production in the EAGLE is shown on Figure 4.

Intermediary goods are produced by monopolistically competitive firms using capital and labour. Monopolistic competition enables firms to set a price for their product in Calvo fashion so that a fraction of the firms can choose their price optimally in each period. Those firms who cannot set the optimal price can index it to a geometric average of past inflation rate and trend inflation rate.

Due to the Calvo mechanism some of the prices are sticky and nominal shocks such as monetary policy shocks are non-neutral. Those firms which cannot set an optimal price will react with changes in the quantity produced to monetary policy shocks.

Final good producers operate in a perfectly competitive market and uses traded, non-traded intermediary goods and the final export good to produce final consumption and investment good.

A distinctive feature of the Hungarian economy is the high import content of export (over the sample 1996-2017 it is about 55 per cent using OECD data) unlike the US or the eurozone. To allow for the high import content of export we introduced a final export good that is made of domestically produced traded and imported intermediary goods and is priced in the currency of the target country (or block of countries).

2.2 HOUSEHOLDS

We distinguish between two types of households in the EAGLE model: the first group called Ricardians have access to the financial markets, can possess physical capital rented out to firms and can also purchase domestic riskless bonds (denominated in local currency) or international bonds denominated in US dollars. Both Ricardians and non-Ricardians supply labour to intermediary firms. The uncovered interest rate parity condition is satisfied in the model. The other group of households are tagged as non-Ricardians who cannot possess financial assets i.e. cannot save or borrow and do not make an intertemporal decision. Non-Ricardians spend their whole disposable income in each period and their consumption expenditure is also subject to a cash-in-advance constraint (the only common feature with Ricardians).

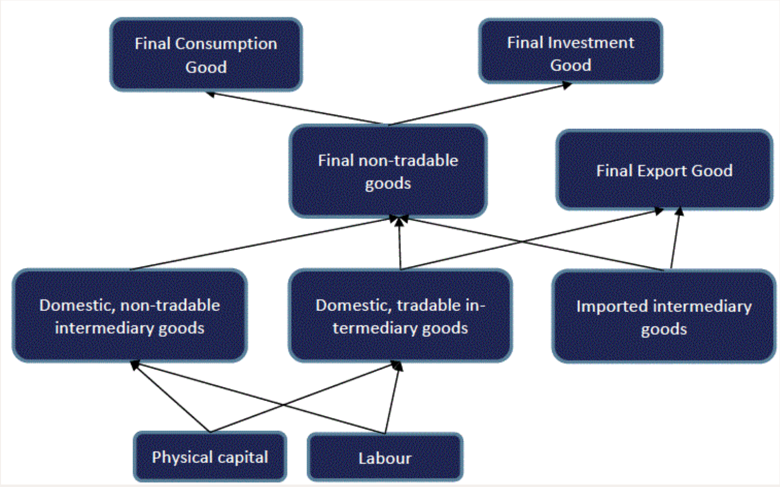
2.3 FISCAL POLICY

The fiscal authority taxes wage income and capital income of households (only Ricardians have capital income) and also taxes consumption expenditures. On the revenue side the fiscal authority issues new bonds. On the expenditure side fiscal policy pays interest rate on existing bond portfolio, government consumption and transfers to households. Fiscal authority operates with a fiscal rule to stabilize debt-to-GDP ratio on a target level consistent with Maastricht criteria. Importantly the debt-to-GDP ratio is settled through lump-sum taxes which are paid by both Ricardian and non-Ricardian households.

2.4 MONETARY POLICY

There is a separate interest rate rule for each block in the EAGLE model. The nominal interest rate responds to the CPI-based annual inflation rate and the growth rate of the quarterly GDP which is one of the possible output gap concept. Some papers

Figure 4
The structure of production in EAGLE



found that the inclusion of the GDP growth instead of some other output gap concept[1] better stabilizes the economy. The interest rate rules (or Taylor rules) are symmetric across the four blocks. The difference can be derived from the different parametrization of the Taylor rule which, for Hungary, places more emphasis on stabilizing the output-gap.

[1] In one concept the output gap is defined as the difference between the sticky-price and the flexible-price measure of output. Another simple definition can be the difference between the sticky-price output and the steady-state output.

3 A description of the EAGLE model

The description of the EAGLE model here focuses on the objectives and constraints of the agents. The full set of equations describing the optimal choices of the agents can be found in the appendix.

3.1 FIRMS

3.1.1 FINAL GOOD PRODUCERS

The final consumption good of company x ($x \in [0, s^H]$) is produced with traded (TT^C) and non-traded (NT^C) intermediary consumption goods through a CES aggregator:

$$Q_t^C(x) = \left[v_C^{\frac{1}{\mu_C}} TT_t^C(x)^{\frac{\mu_C - 1}{\mu_C}} + (1 - v_C)^{\frac{1}{\mu_C}} NT_t^C(x)^{\frac{\mu_C - 1}{\mu_C}} \right]^{\frac{\mu_C}{\mu_C - 1}}, \tag{1}$$

where v_C denotes the weight of the intermediary traded goods in the basket and μ_C is the intratemporal elasticity of substitution between traded and non-traded intermediary goods. The size of the four region is normalized to one. The $[0, s^H]$ interval refers to the domestic (H) region. In a given region there is a continuum number of firms.

The traded intermediary consumption good is a CES-aggregate of home-produced (HT^C) and imported intermediary consumption goods ($\widetilde{IM}_t^C$):

$$TT_t^C(x) = \left[v_{TC}^{\frac{1}{\mu_{TC}}} HT_t^C(x)^{\frac{\mu_{TC} - 1}{\mu_{TC}}} + (1 - v_{TC})^{\frac{1}{\mu_{TC}}} \widetilde{IM}_t^C(x)^{\frac{\mu_{TC} - 1}{\mu_{TC}}} \right]^{\frac{\mu_{TC}}{\mu_{TC} - 1}}, \tag{2}$$

where v_{TC} is the weight of domestically produced goods and μ_{TC} denotes the intratemporal elasticity of substitution between domestically produced and imported intermediary consumption goods.

Similar structure can be written for final non-traded investment goods which are also made up of home-produced, non-traded and imported intermediary investment goods.

The home-produced traded intermediary consumption goods can be aggregated through a CES technology:

$$HT_t^C(x) = \left[\left(\frac{1}{s_H} \right)^{\frac{1}{\theta_T}} \int_0^{s^H} \left(HT_t^C(x, h) \right)^{\frac{\theta_T - 1}{\theta_T}} dh \right]^{\frac{\theta_T}{\theta_T - 1}}$$

The import of intermediary consumption goods is subject to an adjustment cost (denoted as $\Gamma_{IM^C,t}$):

$$\widetilde{IM}_t^C = \left(1 - \Gamma_{IM^C,t} \left(\frac{IM_t^C(x)}{Q_t^C(x)} \right) \right) IM_t^C$$

The import adjustment cost takes the following quadratic form:

$$\Gamma_{IM^C,t} \left(\frac{IM_t^C}{Q_t^C} \right) = \frac{\gamma_{IMC}}{2} \left(\frac{IM_t^C(x)/Q_t^C(x)}{IM_{t-1}^C(x)/Q_{t-1}^C(x)} - 1 \right)^2 \tag{3}$$

Consumption-good import of the domestic block (H) from the three other regions (CO) are assembled through the following CES aggregator:

$$IM_t^C = \left[\sum_{CO \neq H} \left(v_{IMC}^{H,CO} \right)^{\frac{1}{\mu_{IMC}}} \left(IM_t^{H,CO}(x) \right)^{\frac{\mu_{IMC} - 1}{\mu_{IMC}}} \right]^{\frac{\mu_{IMC}}{\mu_{IMC} - 1}} \tag{4}$$

where the bilateral imports for each product (denoted by f^{CO}) are summed up through the following aggregator:

$$IM_t^{C,H,CO}(x) = \left[\int_0^{s^{CO}} \left(IM_t^{C,H}(x,f^{CO})\right)^{\frac{\theta_T - 1}{\theta_T}} df^{CO}\right]^{\frac{\theta_T}{\theta_T - 1}}$$

where it is true that $\Sigma_{CO \neq H} v_{IM^c}^{CO} = 1$ and $CO \neq H$ means that there is no import from the same region.

To aggregate the imports of the export goods from other countries we use:

$$IM_t^X = \left[\sum_{CO \neq H} \left(v_{IMX}^{H,CO}\right)^{\frac{1}{\mu_{IMX}}} \left(IM_t^{H,CO}(x)\right)^{\frac{\mu_{IMX}-1}{\mu_{IMX}}}\right]^{\frac{\mu_{IMX}}{\mu_{IMX}-1}} \tag{5}$$

The aggregator of the export good varieties in bilateral relation H and CO is given by:

$$IM_t^{X,H,CO}(x) = \left[\int_0^{s^{CO}} \left(IM_t^{X,H}(x,f^{CO})\right)^{\frac{\theta_X - 1}{\theta_X}} df^{CO}\right]^{\frac{\theta_X}{\theta_X - 1}},$$

where θ_X denotes elasticity of substitution between varieties of imported goods.

The export good (produced by firm h) is made of home-produced tradable and imported export goods:

$$X_t(h) = \left[\nu_X^{\frac{1}{\mu_X}} HT_t^X(h)^{\frac{\mu_X - 1}{\mu_X}} + (1-\nu_X)^{\frac{1}{\mu_X}} IM_t^X(h)^{\frac{\mu_X - 1}{\mu_X}}\right]^{\frac{\mu_X}{\mu_X - 1}}$$

Based on the cost-minimization problem of the final consumption good producer one can derive the demand for traded, imported and non-traded intermediary consumption goods. Company x producing the final consumption good minimizes the following cost:

$$P_{HT,t}HT_t^C + P_{IM^c,t}IM_t^C + P_{NT,t}NT_t^C$$

subject to the technologies above (see equations 1 and 2) and taking input prices ($P_{HT,t}$, $P_{IM^c,t}$, $P_{NT,t}$) as given.

The cost-minimisation problem implies the following demand functions for home-traded (HT^C), imported (IM^C), and non-traded (NT^C) consumption good of company x:

$$HT_t^C(x) = v_{TC}v_C\left(\frac{P_{HT,t}}{P_{TT^c,t}}\right)^{-\mu_{TC}}\left(\frac{P_{TT^c,t}}{P_{C,t}}\right)^{-\mu_C} Q_t^C(x),$$

$$IM_t^C(x) = (1-v_{TC})v_C\left(\frac{P_{IM^c,t}}{P_{TT^c,t}}\right)^{-\mu_{TC}}\left(\frac{P_{TT^c,t}}{P_{C,t}}\right)^{-\mu_C} Q_t^C(x),$$

$$NT_t^C(x) = (1-v_C)\left(\frac{P_{NT,t}}{P_{C,t}}\right)^{-\mu_C} Q_t^C(x).$$

For product x the bilateral import demand of country C from country CO is given by:

$$IM_t^{C,CO}(x) = v_{IM^C}^{H,CO}\left(\frac{P_{IM,t}^{H,CO}}{P_{IM^c,t}\Gamma_{IM^C}^{C,CO\dagger}(IM_t^{C,CO}(x)/Q_t^C(x))}\right)^{-\mu_{IMC}} \frac{IM_t^C(x)}{1-\Gamma_{IM^C}^{C,CO}(IM_t^{C,CO}(x)/Q_t^C(x))},$$

where parameter $v_{IM^C}^{H,CO}$ (H is the home region which is Hungary in our example; CO can be any of the rest three blocks) can be calculated from the trade matrix (see appendix). $P_{IM,t}^{H,CO}$ is a bilateral import price index showing the import price of the home country from region CO.

$\Gamma_{IM^C}^{C,CO\dagger}$ denotes the adjustment cost function of consumption good import between blocks C and CO. $\Gamma_{IM^C}^{C,CO}$ stands for the quadratic term in the import adjustment cost function (see equation 3 above).

The implied cost-minimising prices are given by:

$$P_{C,t} = \left[v_C P_{TT^C,t}^{1-\mu_C} + (1-v_C) P_{NT,t}^{1-\mu_C}\right]^{\frac{1}{1-\mu_C}}$$

$$P_{TT^C,t} = \left[v_{TC} P_{HT,t}^{1-\mu_{TC}} + (1-v_{TC}) P_{IM^C,t}^{1-\mu_{TC}}\right]^{\frac{1}{1-\mu_{TC}}}$$

$$P_{IM^C,t} = \left(\sum_{CO \neq H} v_{IM^C}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{\Gamma_{IM^C}^{C,CO\dagger}(IM_t^{C,CO}(x)/Q_t^C(x))}\right)^{1-\mu_{IMC}}\right)^{\frac{1}{1-\mu_{IMC}}}$$

It is important to note that the previous equations can also be derived in the case of the investment as well as export good. The latter is also produced from traded and imported intermediary goods.

3.1.2 INTERMEDIARY GOODS PRODUCERS

For a representative product (or firm) h the traded intermediary good is produced with a Cobb-Douglas technology:

$$Y_{T,t}^S(h) = \max\left\{Z_{T,t}\left(K_{T,t}^D(h)\right)^{\alpha_T}\left(N_{T,t}^D(h)\right)^{1-\alpha_T} - \psi_T, 0\right\}$$

where Z_T stands for the productivity in the tradable sector, $K_{T,t}^D$ and $N_{T,t}^D$ are the capital and labour demand, and ψ_T is the fixed-cost in the tradable sector. α_T and $1-\alpha_T$ denote the share of capital and labour in the production of tradable intermediary goods. It is important to note that similar technology and inputs are applied in the production of non-traded goods.

The aggregate labour demand can be defined as:

$$N_t^D = \left[(1-\omega)^{\frac{1}{\eta}}(N_{I,t}^D)^{\frac{\eta-1}{\eta}} + \omega^{\frac{1}{\eta}}(N_{J,t}^D)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

where $N_{I,t}^D$ and $N_{J,t}^D$ denote the labour demand of Ricardian and non-Ricardian households, respectively:

$$N_{I,t}^D = \left[\left(\frac{1}{s^H(1-\omega)}\right)^{\frac{1}{\eta_I}} \int_0^{s^H(1-\omega)} (N_t^D(i))^{\frac{\eta_I-1}{\eta_I}} di\right]^{\frac{\eta_I}{\eta_I-1}}$$

$$N_{J,t}^D = \left[\left(\frac{1}{s^H\omega}\right)^{\frac{1}{\eta_J}} \int_{s^H(1-\omega)}^{s^H\omega} (N_t^D(i))^{\frac{\eta_J-1}{\eta_J}} di\right]^{\frac{\eta_J}{\eta_J-1}}$$

The cost-minimisation problem of the companies producing traded intermediary goods can be written as:

$$\min\left\{R_t^K K_{T,t}^D(h) + W_{T,t} N_{T,t}^D(h)\right\}$$

The cost-minimisation problem yields the following first-order conditions:

$$R_t^K = \alpha_T \frac{Y_{T,t}^S(h) + \psi_T}{K_{T,t}^D(h)} MC_{T,t}(h)$$

$$(1+\tau_t^{W_f})W_t = (1-\alpha_T)\frac{Y_{T,t}^S(h) + \psi_T}{N_{T,t}^D(h)} MC_{T,t}(h)$$

$$MC_{T,t}(h) = \frac{1}{\alpha_T^{\alpha_T}(1-\alpha_T)^{1-\alpha_T}}(R_t^k)^{\alpha_T}[(1+\tau_t^{W_f})W_t]^{(1-\alpha_T)}$$

Similar conditions can be derived in the case of non-traded goods. It is important to note that the marginal cost of the final export good can be derived analogously (see also the appendix of the working paper version of Brozoza-Brezina et al. (2014)).

The above first-order conditions imply the following labour demand schedules for Ricardian and non-Ricardian labour by a representative firm in the tradable sector (h):

$$N_t^D(h,i) = \frac{1}{s^H(1-\omega)} \left(\frac{W_t(i)}{W_{I,t}}\right)^{-\eta_I} \left(\frac{W_{I,t}}{W_t}\right)^{-\eta} N_t^D(h)$$

$$N_t^D(h,j) = \frac{1}{s^H\omega} \left(\frac{W_t(j)}{W_{J,t}}\right)^{-\eta} \left(\frac{W_{J,t}}{W_t}\right)^{-\eta} N_t^D(h)$$

Similar functions can be derived for the labour demand in the non-tradable sector.

The wage indices in the case of Ricardian and non-Ricardian households are given, respectively, by:

$$W_{I,t} = \left[\left(\frac{1}{s^H(1-\omega)}\right)^{\frac{1}{\eta_I}} \int_0^{s^H(1-\omega)} (N_t^D(i))^{1-\eta_I} di\right]^{\frac{1}{1-\eta_I}}$$

$$W_{J,t} = \left[\left(\frac{1}{s^H\omega}\right)^{\frac{1}{\eta_J}} \int_{s^H(1-\omega)}^{s^H\omega} (N_t^D(j))^{1-\eta_J} dj\right]^{\frac{1}{1-\eta_J}}$$

The aggregate wage index for the whole economy can be written as:

$$W = [(1-\omega)(W_{I,t})^{1-\eta} + \omega(W_{J,t})^{1-\eta}]^{\frac{1}{1-\eta}}$$

The total demand for Ricardian (i) labour in case of a representative firm producing tradable (h) and non-tradable (n) good can be written as:

$$\int_0^{s^H} N_t^D(h,i)dh + \int_0^{s^H} N_t^D(n,i)dn$$
$$= \left(\frac{W_t(i)}{W_{I,t}}\right)^{-\eta_I} \left(\frac{W_{I,t}}{W_t}\right)^{-\eta} N_t^D.$$

where $W_{I,t}$ and W_t are defined as above. Similar expression can be written for the case of non-Ricardian (j) households.

3.1.3 PRICING OF INTERMEDIARY FIRMS

We make two assumptions about the pricing of firms producing intermediary products: i) they set product in the currency of the export market (pricing-to-market); ii) those firms who cannot choose their price optimally can index either with previous period inflation to the extent of χ_H or they can adjust their price with fraction $1-\chi_H$ to trend inflation ($\bar{\Pi}$).

Formally, indexation can be written as:

$$P_{HT,t}(h) = (\Pi_{HT,t-1})^{\chi_H}\bar{\Pi}^{1-\chi_H}P_{HT,t-1}(h)$$

The previous expression is true not only for countries producing for the domestic market but also for those exporting:

$$P_{X,t}^{CO}(f^{CO}) = (\Pi_{X,t-1}^{CO,H})^{\chi_X}\bar{\Pi}^{1-\chi_X}P_{X,t-1}^{CO}(f^{CO})$$

Similar expression can be written for firms producing non-tradable products.

Calvo-pricing is presented for profit-maximising firms producing for either domestic or export markets (similar expression is true for those producing non-tradable goods). A firm which had the opportunity to choose its price optimally at time t maximizes its discounted profits between t and $t+k$ with the assumption that the last optimally chosen price will not change with probability ξ_H between t and $t+k$ (and similarly for exporters whose Calvo probability is denoted with ξ_X):

$$\sum_{k=0}^{\infty} \Lambda_{I,t,t+k} \begin{bmatrix} (\xi_H)^k \{P_{H,t+k}(h)HT_{t+k}(h) - TC_{T,t+k}(HT_{t+k} + \psi_T) \\ + \sum_{CO \neq H} (\xi_X)^k \{S_{t+k} P^{CO}_{X,t+k}(h) X^{CO}_{t+k}(h) \\ -TC_{T,t+k}(X^{CO}_{t+k}(h) + \psi_T)\} \end{bmatrix}$$

The first row in the above expression shows the profit from selling on the domestic market, while the second and third row refer to exporters who are pricing in the currency of the destination market ($CO \neq H$ refers to the fact that exporter and the importer cannot be the same; a firm in a particular block can export to three other blocks). $\Lambda_{I,t,t+k}$ denotes the stochastic discount factor which can derived from the utility maximization problem of Ricardians who have an intertemporal perspective. TC stands for total costs. The optimal price set by the intermediaries is subject to mark-up shocks which can be attributed to unexpected changes in energy (e.g. oil) prices, for example (see the reduction in oil prices in one of the policy simulations below). The above profit-maximisation problem is subject to price-indexation and demand of individual products.

A similar profitmaximisation problem can be written for the production of the tradable intermediary good which is used in the production of the export good.

3.2 HOUSEHOLDS

There are two types of households in the model: Ricardians (I) and non-Ricardians (J). The former are indexed with $i \in [0, s^H(1-\omega)]$ while the latter are defined on the interval $j \in [s^H(1-\omega), s^H]$ and $0 < \omega < 1$ is the share of non-Ricardians. Ricardians hold financial assets such as domestically issued and international bonds (denominated in domestic currency and US dollars, respectively) and physical capital. Financial assets help Ricardian smooth their consumption while non-Ricardians cannot hold assets (no saving/borrowing possible) so they consume all their disposable income in a given period. Both types of households need cash to purchase consumption goods (cash in advance assumption).

3.2.1 RICARDIANS

Ricardians maximise utility derived from consumption and leisure on an infinite horizon:

$$E_t \left[\sum_{k=0}^{\infty} \beta^k \left(\frac{1-\kappa}{1-\sigma} \left(\xi_t \frac{C_{I,t+k}(i) - \kappa C_{I,t+k-1}}{1-\kappa} \right)^{1-\sigma} - \frac{1}{1+\zeta} N^{1+\zeta}_{I,t+k} \right) \right]$$

where E_t denotes expectation operator on an information set until t, β is the discount factor, σ is risk-aversion (inverse of the intertemporal elasticity of substitution), ζ is the inverse of Frisch elasticity and κ measures habits in consumption. C_I and N_I denote, respectively, consumption and labour supply (1− leisure) of Ricardians with the assumption that the time frame is normalized to one. ξ_t denotes the consumption preference shock (the slow-down of developing countries is modelled through a reduction in consumption preferences).

The budget constraint of a representative Ricardian household is given by:

$$\begin{aligned} &(1 + \tau^C_t + \Gamma_v(v_t(i)))P_t C_t(i) + P_{I,t} I_t(i) + R_t^{-1} B_{t+1}(i) \\ &+ \left(\left(1 - \Gamma^*_B \left(\frac{S^{H,US}_t B^*_{t+1}}{P_{Y,t} Y_t}; rp_t \right) \right) R^*_t \right)^{-1} S^{H,US}_t B^*_{t+1}(i) + M_t(i) + \Phi_t(i) + \Xi_t \\ &= (1 - \tau^N_t - \tau^W_t) W_t N_t + (1 - \tau^K_t)(R_{K,t} u_t(i) - \Gamma_u(u_t(i)) P_{I,t}) K_t(i) \\ &+ \tau^K_t \delta P_{I,t} K_t(i) + (1 - \tau^D_t) D_t(i) + TR_t(i) - T_t(i) \\ &+ B_t(i) + S^{H,US}_t B^*_t(i) + M_{t-1}(i) \end{aligned}$$

where $P_{C,t}$ and $P_{I,t}$ denote respectively the price of one unit of consumption and investment good. $D_t(i)$ stands for dividends (profits) received by Ricardians only. $TR_t(i)$ are lump-sum transfers, while $T_t(i)$ are lump-sum taxes. $I_t(i)$ is for investment. $M_t(i)$

is cash need to purchase consumption goods (cash in advance assumption to motivate the inclusion of money in the model). $S_t^{H,US}$ is the nominal exchange i.e. the domestic currency price of one unit of US dollars. δ is the depreciation rate of physical capital.

R_t and R_t^* denote the returns on domestic $B_{t+1}(i)$ and international $B_{t+1}^*(i)$ riskless bonds. The returns are already known in t and will be paid out at the beginning of period $t+1$. The international bond is denominated in US dollars. Changing the international bond portfolio is possible after paying an adjustment cost denoted by $\Gamma_{B^*}\left(\frac{S_t^{H,US}B_{t+1}^*}{P_{Y,t}Y_t};rp_t\right)$ and which take the following functional form:

$$\left(\frac{S_t^{H,US}B_{t+1}^*}{P_{Y,t}Y_t};rp_t\right) = \gamma_{B^*}\left[\exp\left(\frac{S_t^{H,US}B_{t+1}^*}{P_{Y,t}Y_t} - \bar{B}_Y^*\right) - 1\right] - rp_t.$$

γ_{B^*} is parameter that helps to set the size of the adjustment cost, $\bar{B}_Y^*$ is the long-term sustainable level of the international bond portfolio. The adjustment cost on the international bond portfolio guarantees a well-defined, unique solution for the steady-state amount of international bonds. In the previous formula rp_t denotes a country-specific risk-premium shock.

The Ricardian household offers labour $N_t(i)$ at the price $W_t(i)$ and rents capital $u_t(i)K_t(i)$ to domestic firms for the rental rate R_t^K. The utilization of capital (denoted by $u_t(i)$) takes the following functional form:

$$\Gamma_u(u_t(i)) = \gamma_{u1}(u_t(i) - 1) + \frac{\gamma_{u2}}{2}(u_t(i) - 1)^2$$

Capital-accumulation is described by:

$$K_{t+1}(i) = (1-\delta)K_t(i) + \left(1 - \Gamma_I\left(\frac{I_t(i)}{I_{t-1}(i)}\right)\right)I_t(i)$$

where the adjustment cost of investment takes a quadratic form:

$$\Gamma_I\left(\frac{I_t(i)}{I_{t-1}(i)}\right) = \frac{\gamma_I}{2}\left(\frac{I_t(i)}{I_{t-1}(i)}\right)^2$$

γ_I helps to set the size of the investment adjustment cost.

Γ_v stands for the adjustment cost paid to purchase consumption goods and is in proportion to the velocity of money that is based on the expenditure of consumption goods:

$$v_t(i) = \frac{(1+\tau_t^C)P_{C,t}C_t(i)}{M_t(i)}$$

Households of type i can set their wage for the labour offered. Wages are sticky in a Calvo fashion so a particular household can set its wage optimally with fixed probability.

Households which cannot set their wage optimally can follow a geometric indexation rule:

$$W_t(i) = \Pi_{C,t-1}^{\chi_I}\bar{\Pi}^{1-\chi_I}W_{t-1}(i)$$

where χ_I shows the weight attached to previous period CPI inflation, while $1-\chi_I$ indicates the weight assigned to trend inflation.

3.2.2 NON-RICARDIANS

A particular non-Ricardian household faces the following budget constraint:

$$\begin{aligned}&(1+\tau_t^C+\Gamma_v(v_t(j)))P_{C,t}C_t(j) + M_t(j)\\&= \left(1-\tau_t^N-\tau_t^{W_h}\right)W_t(j)N_t(j) + TR_t(j) - T_t(j) - M_{t-1}(j)\end{aligned}$$

where notations are similar to those in the case of the Ricardian household. For instance, Γ_v is the adjustment cost related to the cash holdings. Both types of households have to use cash to purchase consumption goods.

3.3 MONETARY AND FISCAL AUTHORITY

Monetary authority. The four blocks in the model share a symmetric interest rate rule:

$$(R_t^{CO})^4 = \phi_R^{CO}(R_{t-1}^{CO})^4 + (1-\phi_R^{CO})[\phi_\pi^{CO}(\Pi_{C,t}^{CO4} - \bar{\Pi}^{CO}) + \phi_Y^{CO}(Y_t^{CO}/Y_{t-1}^{CO} - 1)] + \varepsilon_{R,t}^{CO}$$

where ϕ_R^{CO} is the parameter of interest rate smoothing, ϕ_π^{CO} is the strength of the response to the inflation gap, while ϕ_Y^{CO} is the response to the output-gap in the Taylor rule. $\bar{\Pi}^{CO4}$ denotes the target inflation rate, and 4 refers to the fact inflation is calculated as an average of quarterly inflation rates. $\varepsilon_{R,t}^{CO}$ is a block-specific iid monetary policy shock. In the above formula output gap is identified with a growth gap that is usual in the literature.

Fiscal authority. The fiscal authority has revenues and expenses. In each block the government consumes (G) non-tradable consumption and investment goods. Government pays lump-sum transfers (TR) and collects lump-sum taxes (T). It also levies taxes on consumption, capital and dividends denoted, respectively, by τ^C, τ^K and τ^D. Personal income tax and social security contributions are denoted, respectively, by τ_t^N and $\tau_t^{W_h}$, while the part of labour taxes paid by the firm are denoted as $\tau_t^{W_f}$.

The budget constraint of the government can be written as (receipts on the right-hand side and expenditures on the left-hand side):

$$\begin{aligned}
&P_{G,t}G_t + TR_t + B_t + M_{t-1} \\
&= \tau_t^C P_{C,t}C_t + \left(\tau_t^N + \tau_t^{W_h}\right)\frac{1}{s^H}\left(\int_0^{s^H(1-\omega)} W_t(i)N_t(i)di + \int_{s^H(1-\omega)}^1 W_t(j)N_t(j)dj\right) \\
&+ \tau_t^{W_f}W_tN_t + \tau_t^K(R_{K,t}u_t - (\Gamma_u(u_t) + \delta)P_{I,t}) + \tau_t^D D_t \\
&+ T_t + R_t^{-1}B_{t+1} + M_t
\end{aligned}$$

where each variable is defined in per capita terms except for hours and wage which are aggregated for the types of households.

Government purchases and transfers are defined relative to steady-state nominal GDP and follow an AR(1) process:

$$\begin{aligned}
g_t &= (1-\rho_g)\bar{g} + \rho_g g_{t-1} + \varepsilon_{g,t} \\
tr_t &= (1-\rho_{tr})\overline{tr} + \rho_{tr} tr_{t-1} + \varepsilon_{tr,t}
\end{aligned}$$

where $\varepsilon_{g,t}$ and $\varepsilon_{tr,t}$ are iid innovations to government spending and transfers.

Stabilization of government debt is achieved by the fiscal rule:

$$\tau_t = \phi_{B_Y}\left(\frac{B_t}{P_Y Y} - \frac{B}{Y}\right),$$

where τ denotes lump-sum taxes relative to steady-state nominal GDP ($T_t/(P_Y Y)$) and $\frac{B}{Y}$ is the target level of government debt-to-GDP ratio that is in line with Maastricht criteria.

3.4 AGGREGATION AND SOME DEFINITIONS

The bilateral real exchange rate between two regions (H and CO) is expressed as fraction of the price index in CO and the price index in H (both denominated in the same currency):

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

where $S_t^{H,CO}$ denotes the bilateral nominal exchange rate.

The bilateral term of trade can be written as:

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

where $P^{H,CO}_{IM,t}$ stands for import price index between H and CO, while $P^{H,CO}_{X,t}$ denotes the export price index (the nominator and the denominator are expressed in the same currency).

For a particular non-tradable product (n) the aggregate resource constraint is:

$$Y^{S}_{N,t}(n) = NT^{C}_{t}(n) + NT^{I}_{N,t}(n) + G_t(n), \ \ \forall n$$

Non-tradable products can be aggregated as:

$$\begin{aligned} Y^{S}_{N,t} &= \frac{1}{s^H}\int_0^{s^H} Y^{S}_{NT,t}(n)dn \\ &= \frac{1}{s^H}\left(\int_0^{s^H}\left(NT^{C}_{t}(n) + NT^{I}_{N,t} + G_t(n)\right)dn\right) \\ &= \frac{1}{s^H}\int_0^{s^H}\left(\frac{P_t(n)}{P_{NT,t}}\right)^{-\theta_T} dnNT_t \\ &= s_{N,t}NT_t \end{aligned}$$

where price-dispersion is defined as:

$$s_{N,t} \equiv \frac{1}{s^H}\int_0^{s^H}\left(\frac{P_t(n)}{P_{NT,t}}\right)^{-\theta_T} dn$$

Similar expression can be written for tradable products with the only exception that government uses only non-tradable products.

The price-dispersion can be written recursively as:

$$s_{N,t} = (1-\xi_N)\left(\frac{P_{NT,t}}{P_{NT,t}}\right)^{-\theta_N} + \xi_N\left(\frac{\Pi_{NT,t}}{\Pi^{\chi_N}_{NT,t-1}\bar{\Pi}^{1-\chi_N}}\right)^{\theta_N} s_{N,t-1}$$

The relative demand for non-tradable product n can be express as:

$$NT_t(n) = NT^{C}_{t}(n) + NT^{I}_{t}(n) + NT^{G}_{t}(n) = \left(\frac{P_{NT,t}(n)}{P_{NT,t}}\right)^{-\theta_N} NT_t$$

The relative demand tradable product h can be written as:

$$HT_t(h) = HT^{C}_{t}(h) + HT^{I}_{t}(h) + HT^{X}(h) = \left(\frac{P_{HT,t}(h)}{P_{HT,t}}\right)^{-\theta_T} HT_t$$

The relative demand for a particular good (f^{CO}) imported from country CO can be expressed as:

$$IM_t(f^{CO}) = IM^{C}_{t}(f^{CO}) + IM^{I}_{t}(f^{CO}) + IM^{X}_{t}(f^{CO}) = \left(\frac{P^{H}_{IM,t}(f^{CO})}{P^{H,CO}_{IM,t}}\right)^{-\theta_T} IM_t$$

where the following relationships hold: $NT_t = NT^C_t + NT^I_t + NT^G_t$, $HT_t = HT^C_t + HT^I + HT^X$, $IM_t = IM^C_t + IM^I_t + IM^X_t$.

A domestically produced tradable good h can either be consumed (or invested) domestically or exported:

$$Y_{T,t}(h) = HT^{C}_{t}(h) + HT^{I}_{t}(h) + \sum_{CO\neq H} HT^{X,H,CO}_{t}(h).$$

where $HT^{X,H,CO}_{t}(h)$ the export demand for a particular good h can be derived from the cost-minimisation problem of firm producing the export good.

After aggregation across varieties (h) we can rewrite the previous market clearing condition as:

$$\begin{aligned}
Y_{T,t} &= \frac{1}{s_H}\int_0^{s_H} Y_{T,t}(h)dh \\
&= \frac{1}{s_H}\left[\int_0^{s_H} HT_t^C(h)dh + \int_0^{s_H} HT_t^I(h)dh + \sum_{CO\neq H}\int_0^{s_H} HT_t^{X,H,CO}(h)dh\right] \\
&= \frac{1}{s_H}\left[\left(HT_t^C + HT_t^I\right)\int_0^{s_H}\left(\frac{P_t(h)}{P_{HT,t}}\right)^{-\theta_X} dh\right] \\
&+ \frac{1}{s_H}\left[\sum_{CO\neq H}\nu_X\left(\frac{MC_{T,t}}{MC_{X,t}}\right)^{-\mu_X} X_t^{X,H,CO}\int_0^{s_H}\left(\frac{P_{X,t}^{H,CO}}{P_{X,t}}\right)^{-\theta_X} dh\right] \\
&= s_{HT,t}(HT_t^C + HT_t^I) + \nu_X\left(\frac{MC_{T,t}}{MC_{X,t}}\right)^{-\mu_X}\sum_{CO\neq H} s_{X,t}^{H,CO} X_t^{H,CO}
\end{aligned}$$

where the third line made use of the relative demands of product h.

For a particular quantity X—expressed in per capital terms—the aggregation for Ricardian (I) and non-Ricardian (J) households:

$$X_t \equiv \frac{1}{s^H}\left(\int_0^{s^H(1-\omega)} X_t(i)di + \int_{s^H(1-\omega)}^{1} X_t(j)dj\right) = (1-\omega)X_{I,t} + \omega X_{J,t},$$

The previous expression can be applied for consumption, cash-holdings, transfers and lump-sum taxes as well:

$$\begin{aligned}
C_t &= (1-\omega)C_{I,t} + \omega C_{J,t}, \\
M_t &= (1-\omega)M_{I,t} + \omega M_{J,t}, \\
TR_t &= (1-\omega)TR_{I,t} + \omega TR_{J,t}, \\
T_t &= (1-\omega)T_{I,t} + \omega T_{J,t}.
\end{aligned}$$

The working paper version of Gomes et al. (2012) contains more information on the description of the model.

4 Calibration

Particular parts of the model (especially the trade matrices, the big ratios[2] and the tax rates) are calculated with the **E**AGLE **C**alibration **H**elp **T**ool (ECHT) other parameters were assigned value based on expert advice by MNB staff. The ECHT mainly uses OECD data. In the next we shortly describe the content of the tables in the appendix.

Table 1. contains parameters describing behaviour of households and firms. There two main departures from the baseline EAGLE model: i) the intertemporal elasticity of substitution ($1/\sigma = 1/0.4$) and ii) the share of non-Ricardian households ($\omega = 0.75$) are both higher in the Hungarian version relative to baseline version of EAGLE (with Germany).

Table 2 contains parameters of real and nominal adjustment costs such as the investment adjustment costs and the Calvo parameters of price-stickiness. It also contains parameters of price and wage indexation. Table 3 includes parameters of the monetary and fiscal rule as well as steady-state tax rates.

Table 4 contains the so-called big ratios such as government consumption as a fraction of the GDP.

Table 5 is comprised of the markups in the tradable and non-tradable sectors as well as markups applied in wage-setting. The latter table also includes the elasticity of substitutions consistent with the markups.

Table 6 displays the whole trade matrix of all types of goods as a share of the GDP for each destination (each row).

Tables 7-9 are the disaggregated form of table 6 i.e. it contains the import of consumption, investment and export good as a function of the GDP for each destination, respectively.

Table 10 displays variables need to for a full characterization of the trade among countries such as the size of the regions and elasticity of substitution between consumption, investment and export goods.

Based on trade matrices in table 7-9 and information in table 10 we can calculate parameters $v_{IMC}^{H,CO}$, $v_{IMI}^{H,CO}$ and $v_{IMX}^{H,CO}$ which show the amount of import of country *H* from country(-block) *CO* as a fraction of its total import (see, e.g., expression 4 which exhibits the bilateral import aggregator for consumption goods).

[2] Big ratios are the private, public consumption, investment and net export as a fraction of GDP.

5 Impulse Response Analysis

Previously we have shown that EAGLE is a useful tool to understand the propagation of global shocks. The implementation of the model can be successful if the results from the model can be compared to the forecasting model that is currently in use at the bank and also the calculations done by MNB experts. The difference in the results between the EAGLE model and the new forecasting model of the bank can be attributed to the detailed trade block in the former.

5.1 SHOCK TO THE GROWTH RATE OF THE DEVELOPING COUNTRIES

The accumulated imbalances and unused excess capacities can cause the deceleration of growth in the Asian region. Several studies pointed out that the slow-down of the Asian region can lower growth in all economies around the world. Through the detailed trade connections between the regions EAGLE can be a powerful tool to analyze the deceleration of the Chinese economy. In the following pictures *New Policy Model* (NPM) is meant to refer to recently developed macroeconomic and forecasting model of the MNB. In the New Model we distinguish between saver and borrower households who do not necessarily feature rational expectations in contrast to previous MNB models where households have rational expectations (Békési et al. (2016)).

The slowdown of developing countries is modelled as a negative consumption preference shock of one per cent. The shock dies out gradually and has similar growth effects on Hungary and the eurozone (see figure 5). Due to the negative shock the output of the eurozone falls by 0.1 per cent. Lower foreign demand makes companies—especially those who produce for export—to hire less labour and decrease production. As a result of lower demand the export of the eurozone to the US and to the region representing developing countries. In Hungary output and inflation drop by 0.2 and 0.1, respectively, per annum.

The same simulation was also carried out by the so-called New Model of the MNB using the same type and size of shock. On picture 5 we compare the results from the EAGLE and the New Model. The output and export declines two times more in the EAGLE model due to the strong trade linkages between the four regions.

5.2 MORE RESTRICTIVE US MONETARY POLICY

Following the financial crises started in 2008 the aggregate demand fell in the US, the unemployment rate has risen. As the inflation rate remained low the Federal Reserve cut the policy rate (the Federal Funds Rate) to record low level (the policy rate hit its zero lower bound). The low interest rate environment and the unconventional monetary policy such as asset purchases helped reinvigorate the economy. The recent favourable trend in the US economy such as higher aggregate spending and declining rate of unemployment raises the probability of further tightening of the monetary policy.

The FOMC predicts the stance of US monetary policy to be tighter than market expectations by 40-45 basis points in two consecutive years (see Figure 6). Next we simulate the effect of the difference between FOMC and market expectations on the economy (see Figure 7).

After the shock the ex-ante real interest rate in the US increases constraining the consumption and investment of optimiser households. Due to lower spending of optimisers firms produce less, demand less labour and, thus, aggregate employment, real wage and output decline. Due to the trade connections lower demand from the US has direct and indirect spill-over effects on the eurozone and Hungary. The direct effect on Hungary is due to the trade between Hungary and the eurozone while the indirect effect concerns Hungary through the workings of US policy on the eurozone.

As a result of subdued income, consumption and investment diminish and the outlook of the export sector becomes grimmer. Following the Fed interest rate hike the return on assets denominated in dollars is more attractive to investors causing a flight from Forint-denominated assets and a depreciation of the Hungarian Forint. However, the depreciation of the Forint and the accompanying gain in competitiveness cannot compensate for the decline in foreign demand.

Figure 5
The effect of a slowdown of the Chinese economy on Hungary

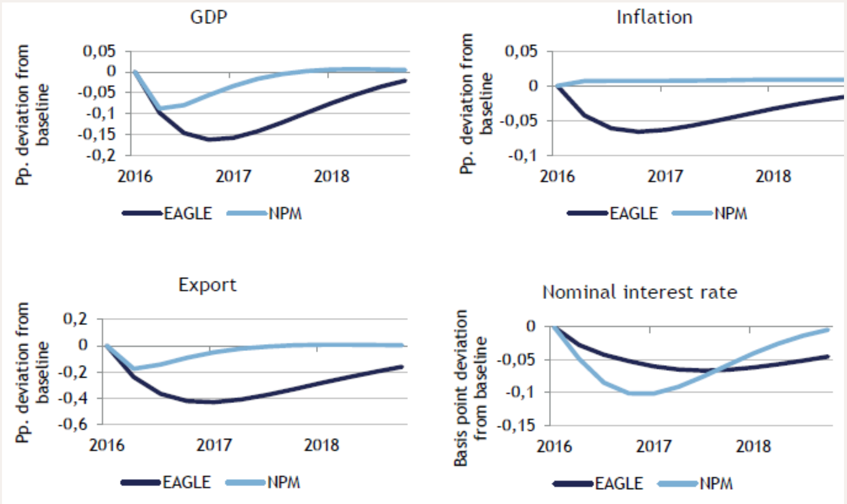


Figure 6
Expectations of the US policy rate by the FOMC and the market

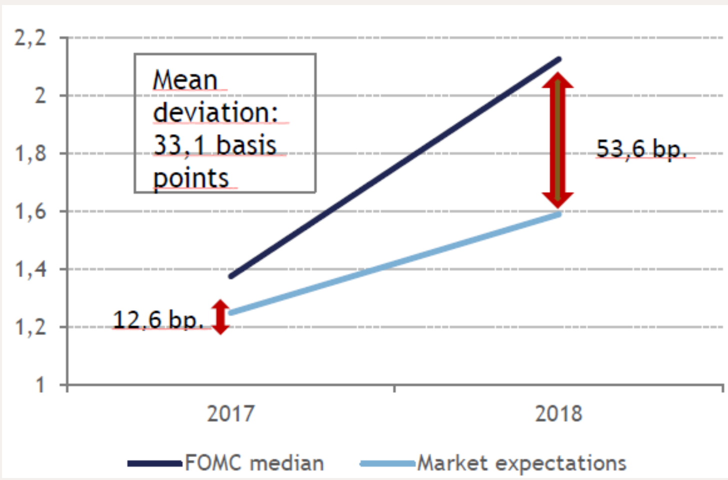
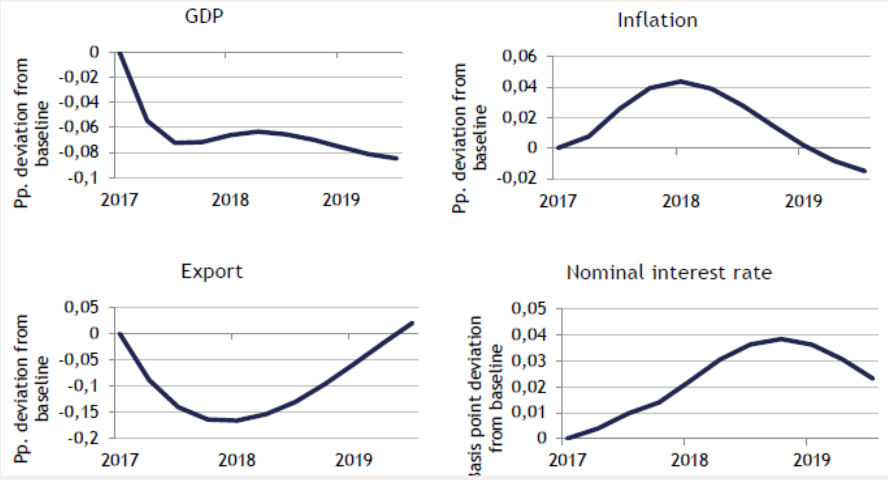


Figure 7
The effects of more restrictive US monetary policy on Hungary



The rise in the Federal Funds Rate causes output in Hungary to contract by 0.1 percent and the export experience a larger 1 per cent drop.

5.3 OIL-PRICE SHOCK

We consider the spill-over effect of a 10 per cent reduction in oil-prices on Hungary (see Figure 8). The fall in the oil-price is modelled as a markup shock (standard in DSGE literature) i.e. an unexpected reduction in the price of the traded good from the region representing developing countries. Due to lower oil-prices the export from developing world to eurozone and to Hungary rises stimulating consumption and economic activity while placing a downward pressure on inflation due to lower input prices in each country blocks.

The Taylor rule prescribes a fall in the nominal interest rate after the reduction in inflation. The expected inflation drops more than the decline inflation leading to a rise in the real interest rate[3]. Higher real interest rate restrains consumption, investment and economic activity overall although each of the indicators is still higher than their initial value during the transition path. In Hungary output rises by 0.2 per cent relative to its long-run value per annum while inflation drops on average by 0.3 per cent per annum. The real effects on the eurozone are quite similar to that of Hungary but the reduction in inflation is smaller (about 0.2 on average) on an annual basis.

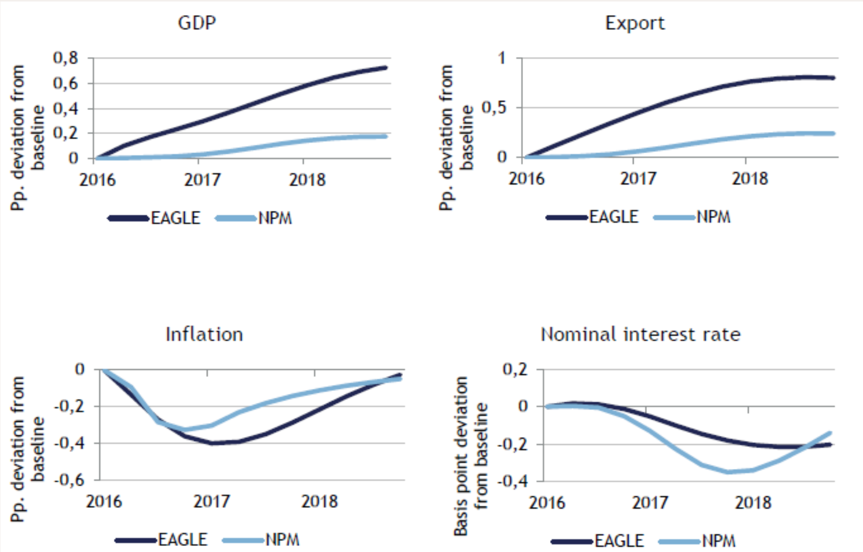
We also carried out the comparison between the EAGLE and the New Model in case of a reduction in oil-prices. The pattern regarding the magnitude of the responses is similar to the previous simulation across the two models. The effects of the oil-price shock are larger in the EAGLE due to detailed trade connections there across regions. In sum, the reduction in the oil-price has positive spill-overs not just on the eurozone but also on Hungary and the rest of the blocks.

5.4 MORE PROTECTIONIST US TRADE POLICY

The new US president's program can cause substantial change in the structure of the US economy. The protectionist view of US economic policy would concern such products which was the engine of US economic growth in the past but the industries which manufacture those products do not contribute substantially to the GDP anymore and can be characterized by reduced capacities and high unemployment. There is substantial uncertainty regarding future measures. In the election campaign there was discussion about a 35 per cent import tariff for the cars manufactured outside the US and there is rumor about further import tariffs on various products.

[3] The real interest rate is defined as the difference between the nominal interest rate and the expected inflation rate (the so-called Fisher relationship).

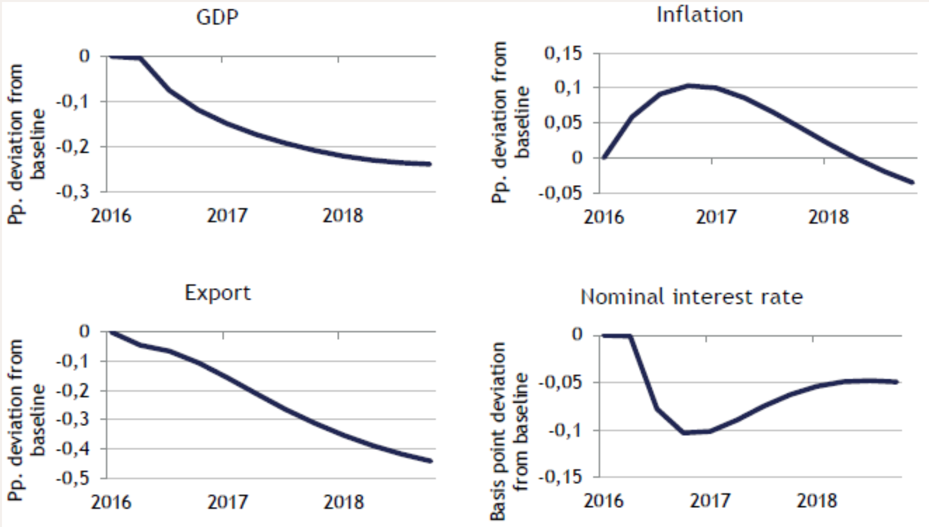
Figure 8
The effects of a 10 per cent reduction in oil prices in the rest of the world on Hungary



We used the EAGLE model to find out what macroeconomic impact the introduction of a more protectionist US trade policy would have on Hungary. The introduction of import tariffs on the goods imported by the US would make import more expensive relative to home produced goods and would lead to a reduction in imports. The eurozone which has strong trade linkages with the US experiences a large drop in exports. Although Hungary is not directly linked to the US through trade but the Hungarian export is negatively impacted due to the tight connections with the eurozone. As the EAGLE model does not contain an import tariff the effects of the tariff are mimicked through a positive shock to import prices prevailing in the US.

Figure 9 reports that lower external demand results in a fall of exports and output. The interest rate rule of each region in the EAGLE model contains—besides the inflation gap—an output gap term which reflects that the monetary authority allows for real economic considerations when setting the policy rate. Due to lower output, the output gap turns to negative and the central bank of Hungary lowers the interest rate which—through the depreciation of the exchange rate—raises inflation. Due to more protectionist US trade policy we predict economic growth in Hungary fall by 0.2 per cent while inflation rise by 0.1 per cent.

Figure 9
The effects of more protectionist US policy on Hungary



6 Conclusions

In recent years there is a continuous update and expansion of the MNB macroeconomic modelling toolbox. In 2016 we introduced the New Macro Model which was developed to reflect to the experience we learnt during the recent financial crises. The next step of the expansion involved the adoption of the EAGLE model for Hungary with special attention to features of the Hungarian economy.

In our macroeconomic forecasting model called New Model the block is representing the domestic economy is very detailed while the foreign block is rather simplified. Therefore, there was interest in developing a model with more detailed foreign sector and which can be used to simulate shocks emerging in the foreign block. Hence, we decided to adopt the EAGLE model which contains four blocks, a global perspective and which was developed in international cooperation.

At the same time we used experience from the New Model when developing the Hungarian block of the EAGLE model. In particular, we took into consideration the role of indebted households in the macroeconomic processes. The parameters of the monetary policy rule are chosen to reflect the considerations of the MNB in supporting economic growth. Further, we made use of recent empirical research which pointed at changes in economic relationships such as the limited exchange rate pass-through and the flattening of the New Keynesian Phillips curve.

In the future we plan to adapt the EAGLE FLI model (EAGLE with **F**inancial **Li**nkages; see Bokan et al. (2015)) to Hungary. In the EAGLE FLI the balance sheet of commercial banks explicitly appear and, thus, it is possible to study the effects of macroprudential policy such as the introduction of higher capital requirements or changes in the loan-to-value (LTV) ratios. The calibration tool for the EAGLE FLI is currently under development at the ECB. The WGEM team treat the Bayesian estimation of the EAGLE model as one of the main priority and there is already some experience with a three-block version of the model. Hence, the estimation of the Hungarian version of the EAGLE model may also be of interest in the future.

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7 Appendix–The full list of model equations and tables

We closely follow the appendix of Gomes et al. (2009) in the description of the full EAGLE model.

7.1 HOUSEHOLD I (RICARDIAN)

- consumption Lagrange multiplier

$$\Lambda_{I,t} = \frac{\left(\xi_t \frac{C_{I,t}-\kappa C_{I,t-1}}{1-\kappa}\right)^{-\sigma}}{1+\tau_t^C+\Gamma_v(v_{I,t})+\Gamma_v'(v_{I,t})v_{I,t}}$$

- bond Euler equations

$$\beta R_t E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\Pi_{C,t+1}^{-1}\right]=1$$

$$\beta R_t^{US}\left(1-\Gamma_{B^*}\left(\frac{S_t^{H,US}B_{t+1}^*}{P_{Y,t}Y_t};rp_t\right)\right)E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\Pi_{C,t+1}^{-1}\frac{S_{t+1}^{H,US}}{S_t^{H,US}}\right]=1$$

$$\Gamma_{B^*}\left(\frac{S_t^{H,US}B_{t+1}^*}{P_{Y,t}Y_t};rp_t\right)=\gamma_{B^*}\left(\exp\left(\frac{S_t^{H,US}B_{t+1}^*}{P_{Y,t}Y_t}-\bar{B}_Y^*\right)-1\right)-rp_t$$

- money holding Euler equation

$$\beta E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\Pi_{C,t+1}^{-1}\right]=1-v_{I,t}^2\Gamma_v'(v_{I,t})$$

$$v_{I,t}(i)=\frac{(1+\tau_t^C)P_{C,t}C_t(i)}{M_t(i)}$$

- capacity utilisation

$$R_{K,t}=\Gamma_u'(u_{I,t}(i))P_{I,t}$$

$$\Gamma_u(u_{I,t}(i))=\gamma_{u1}(u_{I,t}(i)-1)+\frac{\gamma_{u2}}{2}(u_{I,t}(i)-1)^2$$

$$\Gamma_u'(u_{I,t}(i))=\gamma_{u1}(u_{I,t}(i)-1)+\gamma_{u2}(u_{I,t}(i)-1)$$

- Capital-accumulation is described by:

$$K_{t+1}(i)=(1-\delta)K_t(i)+\left(1-\Gamma_I\left(\frac{I_t(i)}{I_{t-1}(i)}\right)\right)I_t(i)$$

$$\Gamma_I\left(\frac{I_t(i)}{I_{t-1}(i)}\right)=\frac{\gamma_I}{2}\left(\frac{I_t(i)}{I_{t-1}(i)}\right)^2$$

$$\Gamma_I'\left(\frac{I_t(i)}{I_{t-1}(i)}\right)=\gamma_I\left(\frac{I_t(i)}{I_{t-1}(i)}\right)\frac{1}{I_{t-1}(i)}$$

- investment in physical capital FOC

$$\frac{P_{I,t}}{P_{C,t}}=Q_{I,t}\left(1-\Gamma_I\left(\frac{I_{I,t}(i)}{I_{I,t-1}(i)}\right)-\Gamma_I\left(\frac{I_{I,t}(i)}{I_{I,t-1}(i)}\right)I_{I,t}(i)\right)$$
$$+\beta E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}Q_{I,t+1}\Gamma_I'\left(\frac{I_{I,t+1}(i)}{I_{I,t}(i)}\right)\frac{I_{I,t+1}^2(i)}{I_{I,t}(i)}\right]$$

- physical capital FOC

$$Q_{I,t} = \beta E_t \left[\begin{array}{c} \frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}(1-\delta)Q_{I,t+1} + (1-\tau^K_{t+1})\frac{R_{K,t+1}}{R_{C,t+1}}u_{I,t+1} \\ +\left(\tau^K_{t+1}\delta - (1-\tau^K_{t+1})\Gamma_u(u_{I,t+1})\right)\frac{P_{I,t+1}}{P_{C,t+1}} \end{array} \right]$$

- wage FOC

$$\left(\frac{\tilde{W}_{I,t}}{P_{C,t}}\right)^{1+\zeta\eta_I} = \frac{\eta_I}{\eta_I - 1}\frac{f_{I,t}}{g_{I,t}}$$

$$f_{I,t} = \left(\frac{W_{I,t}}{P_{C,t}}\right)^{(1+\zeta)\eta_I}\left(N^D_{I,t}\right)^{1+\zeta} + \beta\xi_I E_t\left[\left(\frac{\Pi_{C,t+1}}{\Pi^{\chi_I}_{C,t}\Pi^{1-\chi_I}}\right)^{(1+\zeta)\eta_I} f_{I,t+1}\right]$$

$$g_{I,t} = \Lambda_{I,t}(1-\tau^N_t - \tau^{W_h}_t)\left(\frac{W_{I,t}}{P_{C,t}}\right)^{\eta_I} N^D_{I,t} + \beta\xi_I E_t\left[\left(\frac{\Pi_{C,t+1}}{\Pi^{\chi_I}_{C,t}\Pi^{1-\chi_I}}\right)^{\eta_I - 1} g_{I,t+1}\right]$$

$$W = \left[(1-\omega)(\Pi^{\chi_I}_{C,t}\Pi^{1-\chi_I}W_{I,t-1})^{1-\eta} + \omega(\tilde{W}_{I,t})^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

$$\Pi_{C,t} \equiv \frac{P_{C,t}}{P_{C,t-1}}$$

7.2 HOUSEHOLD J (NON-RICARDIAN)

- consumption Lagrange multiplier

$$\Lambda_{J,t} = \frac{\left(\xi_t\frac{C_{J,t}-\kappa C_{J,t-1}}{1-\kappa}\right)^{-\sigma}}{1+\tau^C_t + \Gamma_v(v_{J,t}) + \Gamma'_v(v_{J,t})v_{J,t}}$$

- money Euler equation

$$\beta E_t\left[\frac{\Lambda_{J,t+1}}{\Lambda_{J,t}}\Pi^{-1}_{C,t+1}\right] = 1 - v^2_{J,t}\Gamma'_v(v_{J,t})$$

$$v_{J,t}(i) = \frac{(1+\tau^C_t)P_{C,t}C_t(i)}{M_t(i)}$$

- Wage FOC

$$\left(\frac{\tilde{W}_{J,t}}{P_{C,t}}\right)^{1+\zeta\eta_J} = \frac{\eta_J}{\eta_J - 1}\frac{f_{J,t}}{g_{J,t}}$$

$$f_{J,t} = \left(\frac{W_{J,t}}{P_{C,t}}\right)^{(1+\zeta)\eta_J}\left(N^D_{J,t}\right)^{1+\zeta} + \beta\xi_J E_t\left[\left(\frac{\Pi_{C,t+1}}{\Pi^{\chi_J}_{C,t}\Pi^{1-\chi_J}}\right)^{(1+\zeta)\eta_J} f_{J,t+1}\right]$$

$$g_{J,t} = \Lambda_{J,t}(1-\tau^N_t - \tau^{W_h}_t)\left(\frac{W_{J,t}}{P_{C,t}}\right)^{\eta_J} N^D_{J,t} + \beta\xi_J E_t\left[\left(\frac{\Pi_{C,t+1}}{\Pi^{\chi_J}_{C,t}\Pi^{1-\chi_J}}\right)^{\eta_J - 1} g_{J,t+1}\right]$$

$$W = \left[(1-\omega)(\Pi^{\chi_J}_{C,t}\Pi^{1-\chi_J}W_{J,t-1})^{1-\eta} + \omega(\tilde{W}_{J,t})^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

7.3 INTERMEDIATE GOODS

- tradables production function

$$Y^S_{T,t}(h) = \max\left\{Z_{T,t}\left(K^D_{T,t}(h)\right)^{\alpha_T}\left(N^D_{T,t}(h)\right)^{1-\alpha_T} - \psi_T, 0\right\}$$

- non-tradables production function

$$Y^S_{NT,t}(h) = \max\left\{Z_{NT,t}\left(K^D_{NT,t}(h)\right)^{\alpha_T}\left(N^D_{NT,t}(h)\right)^{1-\alpha_T} - \psi_{NT}, 0\right\}$$

- tradables marginal cost

$$MC_{T,t}(h) = \frac{1}{\alpha_T^{\alpha_T}(1-\alpha_T)^{1-\alpha_T}}(R_t^k)^{\alpha_T}[(1+\tau_t^{W_f})W_t]^{(1-\alpha_T)}$$

- non-tradables marginal cost

$$MC_{NT,t}(h) = \frac{1}{\alpha_{NT}^{\alpha_{NT}}(1-\alpha_{NT})^{1-\alpha_{NT}}}(R_t^k)^{\alpha_{NT}}[(1+\tau_t^{W_f})W_t]^{(1-\alpha_{NT})}$$

- marginal cost of the exported goods

$$MC_{X,t} = \left[\nu_X MC_{T,t}^{1-\mu_X} + (1-\nu_X)P_{IM^X,t}^{1-\mu_X}\right]^{\frac{1}{1-\mu_X}}$$

- demand for capital

$$R_t^K = \alpha_T \frac{Y_{T,t}^S(h)+\psi_T}{K_{T,t}^D(h)} MC_{T,t}(h)$$

$$R_t^K = \alpha_{NT} \frac{Y_{NT,t}^S(h)+\psi_{NT}}{K_{NT,t}^D(h)} MC_{NT,t}(h)$$

- demand for labour

$$(1+\tau_t^{W_f})W_t = (1-\alpha_T)\frac{Y_{T,t}^S(h)+\psi_T}{N_{T,t}^D(h)} MC_{T,t}(h)$$

$$(1+\tau_t^{W_f})W_t = (1-\alpha_{NT})\frac{Y_{NT,t}^S(h)+\psi_{NT}}{N_{NT,t}^D(h)} MC_{NT,t}(h)$$

$$N_t^D(h,i) = \frac{1}{s^H(1-\omega)}\left(\frac{W_t(i)}{W_{I,t}}\right)^{-\eta_I}\left(\frac{W_{I,t}}{W_t}\right)^{-\eta} N_t^D(h)$$

$$N_t^D(h,j) = \frac{1}{s^H\omega}\left(\frac{W_t(j)}{W_{J,t}}\right)^{-\eta}\left(\frac{W_{J,t}}{W_t}\right)^{-\eta} N_t^D(h)$$

$$W_{I,t} = \left[\left(\frac{1}{s^H(1-\omega)}\right)^{\frac{1}{\eta_I}}\int_0^{s^H(1-\omega)} (N_t^D(i))^{1-\eta_I} di\right]^{\frac{1}{1-\eta_I}}$$

$$W_{J,t} = \left[\left(\frac{1}{s^H\omega}\right)^{\frac{1}{\eta_J}}\int_{s^H(1-\omega)}^{s^H\omega} (N_t^D(j))^{1-\eta_J} dj\right]^{\frac{1}{1-\eta_J}}$$

$$W_t = [(1-\omega)(W_{I,t})^{1-\eta} + \omega(W_{J,t})^{1-\eta}]^{\frac{1}{1-\eta}}$$

$$N_t = [(1-\omega)(N_{I,t})^{1-\eta} + \omega(N_{J,t})^{1-\eta}]^{\frac{1}{1-\eta}}$$

- tradables pricing (domestic market)

$$\frac{\tilde{P}_{HT,t}}{P_{HT,t}} = \frac{\theta_T}{\theta_T - 1}\frac{f_{H,t}}{g_{H,t}} + markup_t^{HT}$$

$$f_{H,t} = HT_t MC_t + \beta\xi_H E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\left(\frac{\Pi_{HT,t+1}}{\Pi_{HT,t}^{\chi_H}\Pi^{1-\chi_H}}\right)^{\theta_T} f_{H,t+1}\right]$$

$$g_{H,t} = P_{HT,t}HT_t + \beta\xi_H E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\left(\frac{\Pi_{HT,t+1}}{\Pi_{HT,t}^{\chi_H}\Pi^{1-\chi_H}}\right)^{\theta_T-1} g_{H,t+1}\right]$$

$$P_{HT,t} = \left[\xi_H\left(\Pi_{HT,t-1}^{\chi_H}\Pi^{1-\chi_H}P_{HT,t-1}\right)^{1-\theta_T} + (1-\xi_H)\left(\tilde{P}_{HT,t}\right)^{1-\theta_T}\right]^{\frac{1}{1-\theta_T}}$$

$$\Pi_{HT,t} = \frac{P_{HT,t}}{P_{HT,t-1}}$$

- tradables pricing (tradable intermediary goods are used for the production of consumption, investment and export goods)

$$\frac{\tilde{P}^{CO,H}_{IM,t}}{P^{CO,H}_{IM,t}} = \frac{\theta_T}{\theta_T - 1}\frac{f^{H,CO}_{X,t}}{g^{H,CO}_{X,t}} + markup^X_t, \text{ for all } CO \neq H$$

$$f^{H,CO}_{X,t} = MC_{T,t}\frac{s^{CO}}{s^H}IM^{CO,H}_t + \beta\xi_X E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\left(\frac{\Pi^{CO,H}_{IM,t+1}}{(\Pi^{CO,H}_{IM,t})^{\chi_X}\Pi^{1-\chi_X}}\right)^{\theta_T} f^{H,CO}_{X,t+1}\right], \text{ for all } CO \neq H$$

$$g^{H,CO}_{X,t} = S^{CO,H}_t P^{CO,H}_{IM,t}\frac{s^{CO}}{s^H}IM^{CO,H}_t + \beta\xi_X E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\left(\frac{\Pi^{CO,H}_{IM,t+1}}{(\Pi^{CO,H}_{IM,t})^{\chi_X}\Pi^{1-\chi_X}}\right)^{\theta_T} g^{H,CO}_{X,t+1}\right], \text{ for all } CO \neq H$$

$$P^{CO,H}_{IM,t} = \left[\xi_X\left((\Pi^{CO,H}_{IM,t-1})^{\chi_X}\Pi^{1-\chi_X}P^{CO,H}_{IM,t-1}\right)^{1-\theta_T} + (1-\xi_X)\left(\tilde{P}^{CO,H}_{IM,t}\right)^{1-\theta_T}\right]^{\frac{1}{1-\theta_T}}$$

- non-tradables pricing

$$\frac{\tilde{P}_{NT,t}}{P_{NT,t}} = \frac{\theta_{NT}}{\theta_{NT}-1}\frac{f_{NH,t}}{g_{NH,t}} + markup^{NT}_t$$

$$f_{NT,t} = NT_t MC_{N,t} + \beta\xi_N E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\left(\frac{\Pi_{NT,t+1}}{\Pi^{\chi_{NT}}_{NT,t}\Pi^{1-\chi_{NT}}}\right)^{\theta_{NT}} f_{NT,t+1}\right]$$

$$g_{NT,t} = P_{NT,t}NT_t + \beta\xi_N E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}}\left(\frac{\Pi_{NT,t+1}}{\Pi^{\chi_{NT}}_{NT,t}\Pi^{1-\chi_{NT}}}\right)^{\theta_{NT}-1} g_{NT,t+1}\right]$$

$$P_{NT,t} = \left[\xi_{NT}\left(\Pi^{\chi_{NT}}_{NT,t-1}\Pi^{1-\chi_{NT}}P_{NT,t-1}\right)^{1-\theta_{NT}} + (1-\xi_N)\left(\tilde{P}_{NT,t}\right)^{1-\theta_{NT}}\right]^{\frac{1}{1-\theta_{NT}}}$$

$$\Pi_{NT,t} = \frac{P_{NT,t}}{P_{NT,t-1}}$$

7.4 FINAL GOOD

- consumption bundle

$$Q^C_t(x) = \left[v_C^{\frac{1}{\mu_C}}TT^C_t(x)^{\frac{\mu_C-1}{\mu_C}} + (1-v_C)^{\frac{1}{\mu_C}}NT^C_t(x)^{\frac{\mu_C-1}{\mu_C}}\right]^{\frac{\mu_C}{\mu_C-1}},$$

$$TT^C_t(x) = \left[v_{TC}^{\frac{1}{\mu_{TC}}}HT^C_t(x)^{\frac{\mu_{TC}-1}{\mu_{TC}}} + (1-v_{TC})^{\frac{1}{\mu_{TC}}}\widetilde{IM}^C_t(x)^{\frac{\mu_{TC}-1}{\mu_{TC}}}\right]^{\frac{\mu_{TC}}{\mu_{TC}-1}},$$

$$HT^C_t(x) = v_{TC}\left(\frac{P_{HT,t}}{P_{TT^c,t}}\right)^{-\mu_{TC}} TT^C_t$$

$$NT^C_t(x) = (1-v_C)\left(\frac{P_{NT,t}}{P_{C,t}}\right)^{-\mu_C} Q^C_t(x)$$

$$IM^C_t = \left[\sum_{CO\neq H}\left(v^{H,CO}_{IMC}\right)^{\frac{1}{\mu_{IMC}}}\left(IM^{H,CO}_t(x)\right)^{\frac{\mu_{IMC}-1}{\mu_{IMC}}}\right]^{\frac{\mu_{IMC}}{\mu_{IMC}-1}}$$

for $\sum_{CO\neq H} v^{CO}_{IM^C} = 1$.

$$IM^{C,CO}_t(x) = v^{H,CO}_{IM^C}\left(\frac{P^{H,CO}_{IM,t}}{P_{IM^c,t}\Gamma^{C,CO\dagger}_{IM^C}(IM^{C,CO}_t(x)/Q^C_t(x))}\right)^{-\mu_{IMC}}\frac{IM^C_t(x)}{1-\Gamma^{C,CO}_{IM^C}(IM^{C,CO}_t(x)/Q^C_t(x))},$$

for all $CO \neq H$.

$$\Gamma^{C,CO}_{IM^C}(IM^{C,CO}_t(x)/Q^C_t(x)) = \frac{\gamma_{IMC}}{2}\left(\frac{IM^{C,CO}_t(x)/Q^C_t(x)}{IM^{C,CO}_{t-1}(x)/Q^C_{t-1}(x)} - 1\right)^2$$

$$\Gamma^{C,CO\dagger}_{IM^C}(IM^{C,CO}_t(x)/Q^C_t(x)) = 1 - \Gamma^{C,CO}_{IM^C}\left(\frac{IM^{C,CO}_t(x)}{Q^C_t(x)}\right) - \left(\Gamma^{C,CO}_{IM^C}\left(\frac{IM^{C,CO}_t(x)}{Q^C_t(x)}\right)\right)' IM^{C,CO}_t$$

- investment bundle

$$Q_t^I(x) = \left[v_I^{\frac{1}{\mu_I}} TT_t^I(x)^{\frac{\mu_I - 1}{\mu_I}} + (1 - v_I)^{\frac{1}{\mu_I}} NT_t^I(x)^{\frac{\mu_I - 1}{\mu_I}} \right]^{\frac{\mu_I}{\mu_I - 1}},$$

$$TT_t^I(x) = \left[v_{TI}^{\frac{1}{\mu_{TI}}} HT_t^I(x)^{\frac{\mu_{TI} - 1}{\mu_{TI}}} + (1 - v_{TI})^{\frac{1}{\mu_{TI}}} \widetilde{IM}_t^I(x)^{\frac{\mu_{TI} - 1}{\mu_{TI}}} \right]^{\frac{\mu_{TI}}{\mu_{TI} - 1}},$$

$$HT_t^I(x) = v_{TI} \left(\frac{P_{HT,t}}{P_{TT^I,t}} \right)^{-\mu_{TI}} TT_t^I$$

$$NT_t^I(x) = (1 - v_I) \left(\frac{P_{NT,t}}{P_{I,t}} \right)^{-\mu_I} Q_t^I(x)$$

$$IM_t^I = \left[\sum_{CO \neq H} \left(v_{IMI}^{H,CO} \right)^{\frac{1}{\mu_{IMI}}} \left(IM_t^{H,CO}(x) \right)^{\frac{\mu_{IMI} - 1}{\mu_{IMI}}} \right]^{\frac{\mu_{IMI}}{\mu_{IMI} - 1}}$$

for $\sum_{CO \neq H} v_{IM^I}^{CO} = 1$.

$$IM_t^{C,CO}(x) = v_{IM^I}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{P_{IM^I,t} \Gamma_{IM^I}^{C,CO\dagger} (IM_t^{C,CO}(x)/Q_t^I(x))} \right)^{-\mu_{IMI}} \frac{IM_t^I(x)}{1 - \Gamma_{IM^I}^{C,CO} (IM_t^{C,CO}(x)/Q_t^I(x))},$$

for all $CO \neq H$.

$$\Gamma_{IM^I}^{C,CO} (IM_t^{C,CO}(x)/Q_t^I(x)) = \frac{\gamma_{IMI}}{2} \left(\frac{IM_t^{C,CO}(x)/Q_t^I(x)}{IM_{t-1}^{C,CO}(x)/Q_{t-1}^I(x)} - 1 \right)^2$$

$$\Gamma_{IM^I}^{C,CO\dagger} (IM_t^{C,CO}(x)/Q_t^I(x)) = 1 - \Gamma_{IM^I}^{C,CO} \left(\frac{IM_t^{C,CO}(x)}{Q_t^I(x)} \right) - \left(\Gamma_{IM^I}^{C,CO} \left(\frac{IM_t^{C,CO}(x)}{Q_t^I(x)} \right) \right)' IM_t^{C,CO}$$

- export good bundle

$$Q_t^X(x) = \left[v_{TX}^{\frac{1}{\mu_{TX}}} HT_t^X(x)^{\frac{\mu_{TX} - 1}{\mu_{TX}}} + (1 - v_{TX})^{\frac{1}{\mu_{TX}}} IM_t^X(x)^{\frac{\mu_{TX} - 1}{\mu_{TX}}} \right]^{\frac{\mu_{TX}}{\mu_{TX} - 1}},$$

$$HT_t^X(x) = v_{TX} \left(\frac{MC_{T,t}}{MC_{X,t}} \right)^{-\mu_X} Q_t^X$$

$$IM_t^X = \left[\sum_{CO \neq H} \left(v_{IMX}^{H,CO} \right)^{\frac{1}{\mu_{IMX}}} \left(IM_t^{H,CO}(x) \right)^{\frac{\mu_{IMX} - 1}{\mu_{IMX}}} \right]^{\frac{\mu_{IMX}}{\mu_{IMX} - 1}}$$

for $\sum_{CO \neq H} v_{IM^X}^{CO} = 1$.

$$IM_t^{C,CO}(x) = v_{IM^I}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{P_{IM^X,t} \Gamma_{IM^X}^{C,CO\dagger} (IM_t^{C,CO}(x)/Q_t^X(x))} \right)^{-\mu_{IMX}} \frac{IM_t^X(x)}{1 - \Gamma_{IM^X}^{C,CO} (IM_t^{C,CO}(x)/Q_t^X(x))},$$

for all $CO \neq H$.

$$\Gamma_{IM^X}^{C,CO} (IM_t^{C,CO}(x)/Q_t^X(x)) = \frac{\gamma_{IMX}}{2} \left(\frac{IM_t^{C,CO}(x)/Q_t^X(x)}{IM_{t-1}^{C,CO}(x)/Q_{t-1}^X(x)} - 1 \right)^2$$

$$\Gamma_{IM^X}^{C,CO\dagger} (IM_t^{C,CO}(x)/Q_t^X(x)) = 1 - \Gamma_{IM^X}^{C,CO} \left(\frac{IM_t^{C,CO}(x)}{Q_t^X(x)} \right) - \left(\Gamma_{IM^X}^{C,CO} \left(\frac{IM_t^{C,CO}(x)}{Q_t^X(x)} \right) \right)' IM_t^{C,CO}$$

- consumption prices

$$P_{C,t} = \left[v_C P_{TT^C,t}^{1-\mu_C} + (1 - v_C) P_{NT,t}^{1-\mu_C} \right]^{\frac{1}{1-\mu_C}}$$

$$P_{TT^C,t} = \left[v_{TC} P_{HT,t}^{1-\mu_{TC}} + (1 - v_{TC}) P_{IM^C,t}^{1-\mu_{TC}} \right]^{\frac{1}{1-\mu_{TC}}}$$

$$P_{IM^C,t} = \left(\sum_{CO \neq H} v_{IM^C}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{\Gamma_{IM^C}^{C,CO\dagger} (IM_t^{C,CO}(x)/Q_t^C(x))} \right)^{1-\mu_{IMC}} \right)^{\frac{1}{1-\mu_{IMC}}}$$

- investment prices

$$P_{I,t} = \left[v_I P_{TT^I,t}^{1-\mu_I} + (1-v_I) P_{NT,t}^{1-\mu_I}\right]^{\frac{1}{1-\mu_I}}$$

$$P_{TT^I,t} = \left[v_{TI} P_{HT,t}^{1-\mu_{TI}} + (1-v_{TI}) P_{IM^I,t}^{1-\mu_{TI}}\right]^{\frac{1}{1-\mu_{TI}}}$$

$$P_{IM^I,t} = \left(\sum_{CO \neq H} v_{IM^I}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{\Gamma_{IM^I}^{C,CO\dagger}(IM_t^{C,CO}(x)/Q_t^I(x))}\right)^{1-\mu_{IMI}}\right)^{\frac{1}{1-\mu_{IMI}}}$$

- export good prices

$$P_{TT^X,t} = \left[v_{TX} P_{HT,t}^{1-\mu_{TX}} + (1-v_{TX}) P_{IM^X,t}^{1-\mu_{TX}}\right]^{\frac{1}{1-\mu_{TX}}}$$

$$P_{IM^X,t} = \left(\sum_{CO \neq H} v_{IM^X}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{\Gamma_{IM^X}^{C,CO\dagger}(IM_t^{C,CO}/Q_t^X)}\right)^{1-\mu_{IMX}}\right)^{\frac{1}{1-\mu_{IMX}}}$$

7.5 MONETARY AND FISCAL AUTHORITIES

- monetary authority

$$(R_t^{CO})^4 = \phi_R^{CO}(R_{t-1}^{CO})^4 + (1-\phi_R^{CO})[\phi_\pi^{CO}(\Pi_{C,t}^{CO4} - \bar{\Pi}^{CO}) + \phi_Y^{CO}(Y_t^{CO}/Y_{t-1}^{CO} - 1)] + \varepsilon_{R,t}^{CO}$$

- fiscal authority

$$\begin{aligned}
&P_{G,t}G_t + TR_t + B_t + M_{t-1} \\
&= \tau_t^C P_{C,t} C_t + \left(\tau_t^N + \tau_t^{W_h}\right)\frac{1}{s^H}\left(\int_0^{s^H(1-\omega)} W_t(i)N_t(i)di + \int_{s^H(1-\omega)}^1 W_t(j)N_t(j)dj\right) \\
&+ \tau_t^{W_f} W_t N_t + \tau_t^K(R_{K,t}u_t - (\Gamma_u(u_t) + \delta)P_{I,t}) + \tau_t^D D_t \\
&+ T_t + R_t^{-1}B_{t+1} + M_t
\end{aligned}$$

$$P_{NT,t}G_t = g_t P_Y Y$$

$$TR_t = tr_t P_Y Y$$

$$T_t = \tau_t P_Y Y$$

$$\tau_t = \phi_{B_Y}\left(\frac{B_t}{P_Y Y} - \frac{B}{Y}\right),$$

Aggregate Variables

$$C_t = (1-\omega)C_{I,t} + \omega C_{J,t}$$

$$M_t = (1-\omega)M_{I,t} + \omega M_{J,t}$$

$$TR_t = (1-\omega)TR_{I,t} + \omega TR_{J,t}$$

$$T_t = (1-\omega)T_{I,t} + \omega T_{J,t}$$

$$C_t = (1-\omega)C_{I,t} + \omega C_{J,t},$$

$$M_t = (1-\omega)M_{I,t} + \omega M_{J,t},$$

$$TR_t = (1-\omega)TR_{I,t} + \omega TR_{J,t},$$

$$T_t = (1-\omega)T_{I,t} + \omega T_{J,t}.$$

$$K_t = (1-\omega)K_{I,t}$$

$$I_t = (1-\omega)I_{I,t}$$

$$D_t = (1-\omega)D_{I,t}$$

$$B_t = (1-\omega)B_{I,t}$$

$$B_t^* = (1-\omega)B_{I,t}^*$$

$$\Gamma_v(v_{J,t}) = (1-\omega)\Gamma_v(v_{I,t}) + \omega\Gamma_v(v_{J,t})$$

$$N_t^D = N_{T,t}^D + N_{N,t}^D$$

$$D_t = P_{Y,t}Y_t - r_t^K K_t - (1+\tau_t^{W_f})W_t N_t^D$$

$$K_t^D = K_{T,t}^D + K_{N,t}^D$$

7.6 MARKET CLEARING CONDITIONS

- final consumption good

$$Q_t^C = C_t + \Gamma_{v,t}$$

- final investment good

$$Q_t^C = I_t + \Gamma_u(u_t)K_t$$

- non-tradable intermediate goods

$$Y_{N,t}^S = s_{N,t}NT_t$$

$$NT_t = NT_t^C + NT_t^I + G_t$$

$$s_{N,t} = (1-\xi_N)\left(\frac{\tilde{P}_{NT,t}}{P_{NT,t}}\right)^{-\theta_N} + \xi_N\left(\frac{\Pi_{NT,t}}{(\Pi_{NT,t})^{\chi_{NT}}\Pi^{1-\chi_{NT}}}\right)^{\theta_N} s_{N,t-1}$$

- tradable intermediate goods

$$Y_t = s_{HT,t}HT_t + \sum_{CO\neq H}\frac{s^{CO}}{s^H}s_{X,t}^{CO}IM_t^{CO,H}$$

$$HT_t = HT_t^C + HT_t^I$$

$$s_{HT,t} = (1-\xi_H)\left(\frac{\tilde{P}_{HT,t}}{P_{HT,t}}\right)^{-\theta_T} + \xi_H\left(\frac{\Pi_{HT,t}}{(\Pi_{HT,t-1})^{\chi_T}\Pi^{1-\chi_T}}\right)^{\theta_T} s_{HT,t-1}$$

$$s_{X,t}^{CO} = (1-\xi_X^{CO})\left(\frac{\tilde{P}_{X,t}^{CO}}{P_{X,t}^{CO}}\right)^{-\theta_X} + \xi_X^{CO}\left(\frac{\Pi_{X,t}^{CO}}{(\Pi_{X^{CO},t-1})^{\chi_X^{CO}}\Pi^{1-\chi_X^{CO}}}\right)^{\theta_X} s_{X,t-1}^{CO}$$

- labour

$$N_{I,t} = s_{I,t}N_{I,t}^D$$

$$N_{J,t} = s_{J,t}N_{J,t}^D$$

$$s_{I,t} = (1-\xi_I)\left(\frac{\tilde{W}_{I,t}}{W_{I,t}}\right)^{-\eta_I} + \xi_I\left(\frac{W_{I,t}}{(W_{I,t-1})^{\chi_I}\Pi^{1-\chi_I}}\right)^{\eta_I} s_{I,t-1}$$

$$s_{J,t} = (1-\xi_J)\left(\frac{\tilde{W}_{J,t}}{W_{J,t}}\right)^{-\eta_J} + \xi_J\left(\frac{W_{J,t}}{(W_{J,t-1})^{\chi_J}\Pi^{1-\chi_J}}\right)^{\eta_J} s_{J,t-1}$$

- capital services

$$u_t K_t = K_t^D$$

- internationally traded bonds

$$\sum_{CO} s^{CO}B_t^{*CO} = 0, \sum_{CO} s^{CO} = 1$$

7.7 RESOURCE CONSTRAINT, TRADE BALANCE AND NET FOREIGN ASSET POSITION

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$$P_{Y,t}Y_t = P_{C,t}Q_t^C + P_{I,t}Q_t^I + P_{NT,t}G_t + \sum_{CO\neq H} S_t^{H,CO}P_{X,t}^{H,CO}X_t^{H,CO} - \sum_{CO\neq H} P_{IM,t}^{H,CO}IM_t^{H,CO}$$

$$IM_t^{H,CO} = IM_t^{C,CO}\frac{1-\Gamma_{IM^C}^{H,CO}(IM_t^{C,CO}/Q_t^C)}{\Gamma_{IM^C}^{H,CO\dagger}(IM_t^{C,CO}/Q_t^C)} + IM_t^{I,CO}\frac{1-\Gamma_{IM^I}^{H,CO}(IM_t^{I,CO}/Q_t^I)}{\Gamma_{IM^I}^{H,CO\dagger}(IM_t^{I,CO}/Q_t^I)}$$

-

$$X_t^{H,CO} = \frac{s^{CO}}{s^H}IM_t^{CO,H}$$

-

$$Y_t = Y_{T,t}^S + Y_{N,t}^S$$

-

$$TB_t = S_t^{H,CO}P_{X,t}^{H,CO}IM_t^{CO,H} - \sum_{CO\neq H} P_{IM,t}^{H,CO}IM_t^{H,CO}$$

-

$$R_{t-1}^{*-1}B_t^* = B_{t-1}^* + \frac{TB_{t-1}}{S_{t-1}^{H,US}}$$

7.8 RELATIVE PRICES

- bilateral real exchange rate

$$RER_t^{H,CO} \equiv \frac{S_t^{H,CO}P_{C,t}^{CO}}{P_{C,t}^H} \text{ for all } CO \neq H.$$

- bilateral terms of trade

$$TOT_t^{H,CO} \equiv \frac{P_{IM,t}^{H,CO}}{S_t^{H,CO}P_{X,t}^{H,CO}} \text{ for all } CO \neq H.$$

- effective real exchange rate

$$REER_t^H = \prod_{CO\neq H}\left(RER_t^{H,CO}\right)^{\nu^{H,CO}}$$

$$\nu^{H,CO} \equiv \frac{P_{X,t}^H X_t^H}{P_{X,t}^H X_t^H + P_{IM,t}^H X_t^H}\nu_X^{H,CO} + \frac{P_{IM,t}^H X_t^H}{P_{X,t}^H X_t^H + P_{IM,t}^H X_t^H}\nu_{IM}^{H,CO}$$

$$\nu_X^{H,CO} \equiv \frac{X_t^{H,CO}}{X_t}\frac{RER_t^{H,CO}P_{Y,t}^{CO}Y_t^{CO}}{RER_t^{H,CO}P_{Y,t}^{CO}Y_t^{CO} + \Sigma_{K\neq\{H,CO\}}RER_t^{H,K}P_{X,t}^K X_t^{K,CO}} + \sum_{K\neq\{H,CO\}}\frac{X_t^{H,K}}{X_t}\frac{RER_t^{H,CO}P_{X,t}^{CO}X_t^{CO,K}}{P_{Y,t}^K Y_t^K + \Sigma_{J\neq K}RER_t^{H,J}P_{X,t}^J X_t^{J,K}}$$

$$\nu_{IM}^{H,CO} \equiv RER_t^{H,CO}\frac{P_{X,t}^{CO}IM_t^{H,CO}}{P_{IM,t}^H IM_t^H}$$

$$P_{IM,t}^H IM_t^H \equiv P_{IM,t}^C IM_t^C + P_{IM,t}^I IM_t^I$$

$$X_t^H \equiv \sum_{CO\neq H}\frac{s^{CO}}{s^H}IM_t^{CO,H}$$

$$X_t^H \equiv \sum_{CO \neq H} \frac{s^{CO}}{s^H} RER_t^{H,CO} P_{X,t}^{H,CO} IM_t^{CO,H}$$

$$P_{IM,t}^H IM_t^H \equiv \sum_{CO \neq H} P_{IM,t}^{H,CO} IM_t^{H,CO}$$

- bilateral exchange rate depreciation in real terms

$$RERDEP_t^{H,CO} \equiv \frac{RER_t^{H,CO}}{RER_{t-1}^{H,CO}}$$

- bilateral exchange rate depreciation in nominal terms

$$NERDEP_t^{H,CO} \equiv \frac{S_t^{H,CO}}{S_{t-1}^{H,CO}} \equiv RERDEP_t^{H,CO} \frac{\Pi_{C,t}^H}{\Pi_{C,t}^{CO}}$$

7.9 SHOCKS

$$g_t = (1-\rho_g)\bar{g} + \rho_g g_{t-1} + \varepsilon_{g,t}$$
$$tr_t = (1-\rho_{tr})\overline{tr} + \rho_{tr} tr_{t-1} + \varepsilon_{tr,t}$$

$$\ln(z_{T,t}) = (1-\rho_{z_T}) \ln(z_T) + \rho_{z_T} \ln(z_{T,t-1}) + \varepsilon_{z_{T,t}}$$
$$\ln(z_{N,t}) = (1-\rho_{z_N}) \ln(z_N) + \rho_{z_N} \ln(z_{N,t-1}) + \varepsilon_{z_{N,t}}$$
$$\tau_t^C = (1-\rho_{\tau^C})\tau^C + \rho_{\tau^C}\tau_{t-1}^C + \varepsilon_{\tau^C,t}$$
$$\tau_t^D = (1-\rho_{\tau^D})\tau^D + \rho_{\tau^D}\tau_{t-1}^D + \varepsilon_{\tau^D,t}$$
$$\tau_t^K = (1-\rho_{\tau^K})\tau^K + \rho_{\tau^K}\tau_{t-1}^K + \varepsilon_{\tau^K,t}$$
$$\tau_t^N = (1-\rho_{\tau^N})\tau^N + \rho_{\tau^N}\tau_{t-1}^N + \varepsilon_{\tau^N,t}$$
$$\tau_t^{W_h} = (1-\rho_{\tau^{W_h}})\tau^{W_h} + \rho_{\tau^{W_h}}\tau_{t-1}^{W_h} + \varepsilon_{\tau^{W_h},t}$$
$$\tau_t^{W_f} = (1-\rho_{\tau^{W_f}})\tau^{W_f} + \rho_{\tau^{W_f}}\tau_{t-1}^{W_f} + \varepsilon_{\tau^{W_f},t}$$
$$rp_t = \rho_{RP} rp_{t-1} + \varepsilon_{RP,t}$$
$$markup_t^i = \rho_{markup} markup_{t-1}^i + \varepsilon_{markup^i,t}, \quad i \in \{HT, NT, X\}$$
$$\xi_t = (1-\rho_\xi)\xi + \rho_\xi \xi_{t-1} + \varepsilon_{\xi_{,t}}$$

Table 1
Parameters describing the behaviour of households and firms

	HU	EA	US	RW
Households				
Discount factor (β)	0.99	0.99	0.99	0.99
Intertemporal elasticity of substitution ($1/\sigma$)	1/0.4	1/0.4	1/0.4	1/0.4
Inverse of Frisch elasticity(ζ)	2	2	2	2
Consumption habits (κ)	0.7	0.7	0.7	0.7
Share of non-Ricardian households (ω)	0.75	0.25	0.25	0.25
Amortisation of physical capital (δ)	0.025	0.025	0.025	0.025
Intermediary goods producers				
El. of subst. between capital and labour	1.00	1.00	1.00	1.00
Share of capital in production (α)	0.3	0.3	0.3	0.3
El. of subst. between Ric. and non-Ric. labour (η)	4.33	4.33	4.33	4.33
Final consumption good producers				
El. of subst. between dom. produced and imported (μ_{TC})	2.50	2.50	2.50	2.50
Weight on dom. produced good (ν_{TC})	0.20	0.20	0.85	0.20
El. of subst. between tradable and non-tradable good (μ_C)	0.50	0.50	0.50	0.50
Weight on dom. produced tradable good (ν_C)	0.78	0.45	0.35	0.35
Final investment good producers				
El. of subst. between dom. produced and imported (μ_{TI})	2.50	2.50	2.50	2.50
Weight on dom. produced good (ν_{TI})	0.20	0.20	0.85	0.20
El. of subst. between tradable and non-tradable good (μ_I)	0.50	0.50	0.50	0.50
Weight on dom. produced tradable good (ν_I)	0.78	0.45	0.35	0.35
Final export good producers				
El. of subst. between dom. produced and imported (μ_X)	2.50	2.50	2.50	2.50
Weight on dom. produced tradable good (ν_X)	0.78	0.45	0.35	0.35

Notes: HU, EA, US, RW denote Hungary, Euro Area, United States and the rest of the world, respectively.

Table 2
Parameters describing real and nominal rigidities

	HU	EA	US	RW
Adjustment costs				
Import adj. cost cons. good (γ_{IM^C})	2.00	2.00	2.00	2.00
Import adj. cost inv. good (γ_{IM^I})	1.00	1.00	1.00	1.00
Capital utilisation (γ_{u2})	2000	2000	2000	2000
Investment adj. cost (γ_I)	6.00	6.00	6.00	6.00
Adj. cost on cash balances (γ_{v1})	0.029	0.029	0.029	0.029
Adj. cost on cash balances (γ_{v2})	0.15	0.15	0.15	0.15
Adj. cost on international bond portfolio (γ_{B^*})	0.01	0.01	...	0.01
Calvo params. of price and wage rigidity				
Wage rig.: Ric. and non-Ric. HHs (ξ_I, ξ_J)	0.75	0.75	0.75	0.75
Price rig.: tradable (ξ_T) and non-tradable (ξ_N)	0.92	0.92	0.75	0.75
Price rig.: exporters (ξ_X)	0.75	0.75	0.75	0.75
Indexation of prices and wages				
Wages: Ric. and non-Ric. HHs. (χ_I és χ_J)	0.75	0.75	0.75	0.75
Prices: dom. tradable and non-tradable. (χ_H és χ_N)	0.50	0.50	0.50	0.50
Prices: exporters (χ_x)	0.50	0.50	0.50	0.50

Table 3
Parameters describing rules of the monetary and fiscal authority as well as steady-state tax rates

	HU	EA	US	RW
Monetary authority				
Inflation target (annualised, $\bar{\Pi}^4$)	1.03	1.02	1.02	1.02
Interest rate smoothing (ϕ_R)	0.87	0.87	0.87	0.87
Strength of the response to inflation gap (ϕ_π)	1.70	1.70	1.70	1.70
Strength of the response to output gap (ϕ_Y)	0.10	0.10	0.10	0.10
Fiscal authority				
Debt/GDP target (quarterly $\bar{B}_Y$)	2.40	2.40	2.40	2.40
Strength of the response to debt/GDP	0.10	0.10	0.10	0.10
Consumption tax (τ^C)	0.22	0.183	0.077	0.077
Tax on dividends (τ^D)	0.15	0.00	0.00	0.00
Tax on capital (τ^K)	0.19	0.19	0.00	0.00
Personal income tax rate (τ^N)	0.15	0.122	0.154	0.154
Tax rate paid by the employer (τ^{W_f})	0.219	0.219	0.071	0.071
Social security (τ^{W_h})	0.118	0.118	0.071	0.071

Table 4
Big ratios

	HU	EA	US	RW
Government purchases	0.66739	0.73661	0.71036	0.59655
Private investment	0.18585	0.17975	0.17034	0.20378
Private consumption	0.66302	0.57333	0.67418	0.55787
Goods and services export	0.75343	0.22241	0.10961	0.13053
Goods and services import	0.74889	0.21035	0.15135	0.10796
Net export	0.00454	0.01206	0.04074	0.02256
Net foreign assets	-0.96886	-0.09815	-0.19656	0.14237

Table 5
Markups in the production of domestic tradables, export goods, non-tradables and in wage-setting

	Domestic tradable	Export good	Non-tradable	Wages
	θ_T	θ_X	θ_{NT}	$\eta_I = \eta_J$
HU	1.20(6.0)	1.20(6.0)	1.50(3.0)	1.30(4.3)
EA	1.20(6.0)	1.20(6.0)	1.50(3.0)	1.30(4.3)
US	1.20(6.0)	1.20(6.0)	1.50(3.0)	1.16(7.3)
RW	1.20(6.0)	1.20(6.0)	1.50(3.0)	1.16(7.3)

Notes: $x(y)$ denotes gross markup (elasticity of substitution) such that $x = y/(y-1)$ is satisfied.

Table 6
Trade matrix for all products as a share of the GDP of the importer)

	HU	EA	US	RW	Total
HU	-	0.415436	0.034682	0.279379	0.729497
EA	0.003884	-	0.025703	0.172803	0.20239
US	0.000177	0.018167	-	0.130983	0.149327
RW	0.000879	0.059857	0.045145	-	0.105881

Notes: each row contains the import of a block from the other three blocks as a share of its own GDP. The last column indicates total imports as a share of the GDP of the importer.

Table 7
Trade matrix of the import of consumption good as a share of the importer's GDP

	HU	EA	US	RW	Total
HU	-	0.051773	0.002599	0.032187	0.086558
EA	0.000729	-	0.002418	0.037416	0.040563
US	2.53E-05	0.003498	-	0.031148	0.034672
RW	0.000203	0.011203	0.005633	-	0.017037

Table 8
Trade matrix of the import of investment good as a share of the importer's GDP

	HU	EA	US	RW	Total
HU	-	0.060429	0.007109	0.037904	0.105442
EA	0.000591	-	0.006334	0.021791	0.028716
US	3.58E-05	0.003591	-	0.020087	0.023713
RW	0.00014	0.012667	0.008978	-	0.021786

Table 9
Trade matrix of the import of the export good as a share of the importer's GDP

	HU	EA	US	RW	Total
HU	-	0.303235	0.024974	0.209288	0.537497
EA	0.002564	-	0.016951	0.113596	0.133111
US	0.000116	0.011077	-	0.079748	0.090942
RW	0.000535	0.035986	0.030537	-	0.067058

Table 10
Further parameters describing trade between blocks

	HU	EA	US	RW
ES among imported cons. goods (μ_{IMC})	2.50	2.50	2.50	2.50
ES among imported inv. goods (μ_{IMI})	2.50	2.50	2.50	2.50
ES among imported good used for export (μ_{IMX})	2.50	2.50	2.50	2.50
Size of the blocks	0.002848	0.16724	0.22598	0.60393

Notes: ES refers to the Elasticity of Substitution.

MNB Working Papers 7

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