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## **Inflation – Harrod-Balassa-Samuelson effect in a DSGE model setting\***

Črt Lenarčič†

### **Abstract**

This paper sets up a two-country two-sector dynamic stochastic general equilibrium model that introduces sector specific productivity shocks with quality improvement mechanism of goods. It provides a model-based theoretical background for the Harrod-Balassa-Samuelson phenomenon that describes the relationship between productivity and price inflation within different sectors of a particular economy. Both, the calibrated and the estimated model are able to show that the induced tradable sector productivity shocks drive the non-tradable and tradable sector price inflation upwards. By doing this, we overcome the problem that the tradable productivity increase in a typical open economy specification reduces the relative price of domestic tradable goods relative to the foreign ones.

*Keywords:* Harrod-Balassa-Samuelson effect, DSGE model, inflation, productivity, quality improvement.

*JEL classification:* C32, E31, E32

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## 1. Introduction

The relationship between productivity and price inflation is described by the theory of the Harrod-Balassa-Samuelson phenomenon (henceforth HBS). Harrod (1933), Balassa (1964) and Samuelson (1964) independently developed and formulated the HBS productivity approach in order to explain the purchasing power parity<sup>1</sup>. The HBS effect represents a tendency for countries that experience a higher tradable-sector productivity growth compared to a non-tradable-sector productivity growth to have higher overall price levels (Obstfeld and Rogoff, 1996). In more detail, the basic idea behind it is that the tradable sector productivity growth influences the growth of wages in the tradable and later on in the non-tradable sector. Wage growth in the tradable sector consequently affects the growth of prices in the non-tradable sector. Depending on the nominal exchange rate regime of a particular economy, it affects the real exchange rate as well. However, Betts and Kehoe (2008) studied the relationship between the real exchange rate and the relative price of non-tradable to tradable goods. Their conclusion is that the relation between the two variables is stronger in an intense trade environment. Therefore, the basic assumption is that the relationship between the relative growth in the productivities of the tradable to non-tradable sector and the relative price of non-tradable to tradable goods is relatively straightforward if we include sectoral data for European countries. In addition to the close trade environment, the sole euro area integration process suppresses the ability of economies to adjust through the nominal exchange rate channel, which could consequently put more pressure on the non-tradable price inflation.

The HBS hypothesis can be tested on different entities, which can in general represent different countries, regions, or in many cases, sectors. In our case, we divide these entities into a tradable sector and a non-tradable sector. We follow a similar principle as the De Gregorio, Giovannini and Wolf's (1994) methodology. They use the ratio of exports to total production to define both sectors. In order to do that we include and combine the NACE Revision 2 10-sector breakdown statistical classification time series data of economic activities with input-output tables in order to calculate the ratio of exports to total production. Input-output tables are available at the World Input-Output Database (WIOD)<sup>2</sup>, while NACE Revision 2 data is available at the Eurostat database, which provides data on labour productivity (gross value added and number of employees) and price levels. By combining and obtaining the relevant tradable and non-tradable data for further analysis and adding other observable macroeconomic data, we estimate the constructed DSGE model.

The problem of permanent tradable productivity increase in a typical dynamic open economy specification is reducing the relative price of domestic tradable goods relative to the foreign ones. This implies worsening the terms of trade for the domestic economy and consequently, its real exchange does not appreciate. These dynamics are not consistent with empirical evidence found for new European Union member states. The main contribution of the paper is to overcome the typical dynamic open economy setting by constructing and estimating a two-country two-sector DSGE model with the quality improvement extension, proposed by Masten (2008) in a smaller calibrated version of a

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<sup>1</sup> Baumol and Bowen (1967) developed a similar model that only describes the relationship between productivity and wages and presents an important part of the HBS hypothesis as was discussed by Wagner and Hlouskova (2004).

<sup>2</sup> In defining the tradable and non-tradable sector we differ from the standard approach used in the literature by excluding those sectors from the analysis, which are not distinctively tradable or non-tradable.

dynamic model. The basic assumption is therefore the separation of the economy into a tradable and non-tradable sector. The tradable sector is open and allows for export domestic goods and import foreign goods. The non-tradable sector is closed to foreign markets (similar structure was used by Masten, 2008; Rabanal, 2009; Micaleff and Cyrus, 2013). The assumption is that the tradable and non-tradable sectors are exposed to different productivity shocks; this means that the non-stationary real variables can grow at a different pace, thus providing a case for the HBS effect. In specifying technology, we allow for quality improvement mechanism, which is needed to replicate the appreciation of prices, without resorting to the unrealistic assumption of perfect competition in the tradable sector (Masten, 2008).

We find the precondition for the occurrence of the HBS effect, based on augmented technology process that considers quality improvement mechanism, which affects marginal costs by requiring the usage of more advanced inputs in the production process. The quality improvement of goods overcomes the typical open economy theoretical specification that reduces the relative prices of domestic tradable goods relative to foreign prices, and consequently worsens the terms of trade for the domestic economy. By introducing a sector-specific domestic tradable technology shock, the modelled economy responds by increasing price differential of non-tradable relative to tradable prices and the overall domestic inflation. Doing this we are able to theoretically explain why the economies that were experiencing higher economic and productivity growth during the catching up phase experienced higher inflation.

In section 2, a review of the HBS related literature is presented and discussed. In section 3, the theoretical framework of the DSGE model is provided. In section 4, the classification and definition of the economic activities into a tradable and non-tradable sector is presented, with which sectoral price indexes and time series of sectoral labour productivity growths are obtained. The calibrated model is presented in section 5, while the estimation results of the DSGE model are given and discussed in section 6. Conclusions are presented in the section 7.

## **2. Literature review**

Despite treating the HBS theory as an old idea, in which the sectoral productivity differential is seen as a possible driver for price inflation in the non-tradable sector (Harrod, 1933; Balassa, 1964; and Samuelson, 1964), the empirical testing of the HBS effect only became more popular in recent years as econometric methods advanced and new (or additional) time series data became available. This availability was largely due to the establishment of the EU and later on its enlargement process together with advances and convergence of methodologies in collecting data by the national statistical offices. At the same time, addressing the HBS issue became relevant from the economic policy perspective in trying to identify different sources of (structural) inflation. Betts and Kehoe (2008) show that the close trade environment lowers the significance of the nominal exchange rate adjustment. This was (and can still be) especially important for the future EU and euro area countries, which are obliged to satisfy the Maastricht criterion of low and stable inflation, as well as for other emerging economies in trying to stabilise their overall inflation.

In their comprehensive survey, Tica and Družić (2006) assembled empirical evidence regarding the HBS effect. They find that most of the empirical work supports the existence

of the HBS effect. Especially strong evidence comes from the work based on the cross-section empirical studies, similar to Balassa's (1964) work. Most of the papers focus on estimating the magnitude of the HBS effect in accession countries in the EU. Čihák and Holub (2001) for instance studied the presence of the HBS effect in the Czech Republic *vis-à-vis* EU countries, while allowing for differences in structures of relative prices. Jazbec (2002) considers Slovenia as the HBS case of an accession country, while Dedu and Dumitrescu (2010) tested the HBS effect using Romanian data. Papers, as from Cipriani (2000), Coricelli and Jazbec (2004), Halpern and Wyplosz (2001), Arratibel, Rodríguez-Palenzuela and Thimann (2002), Breuss (2003), Wagner and Hlouskova (2004), Mihaljek and Klau (2008), consider a larger accession country panel. Some of the work focuses also on emerging economies. Jabeen, Malik and Haider (2011) tested the HBS hypothesis on Pakistani data, while Guo and Hall (2010) tested HBS the effect on Chinese regional data.

The empirical strand of the HBS effect related literature opened up new questions regarding data issues and were related mostly to availability in reliability of sectoral data. As databases, especially in Europe, had become more complete, new available data also made it possible to study the presence of the HBS effect between individual tradable and non-tradable sectors of a particular economy. Since it is difficult to clearly divide between the tradable and non-tradable commodities in the real world, some of the early papers tried to identify the tradability/non-tradability of commodities. Officer (1976) proposed that manufacturing and/or industry in theory belong in the tradable sector, while the services belong in the non-tradable sector. Further on, De Gregorio, Giovannini and Wolf (1994) used a ratio of exports to total production of each sector to define both sectors.

In the empirical studies mostly total factor productivity (TFP) or average productivity of labour are used. Marston (1987), De Gregorio, Giovannini and Wolf (1994), De Gregorio and Wolf (1994), Chinn and Johnston, (1997), Halikias, Swagel and Allan (1999), Kakkar (2002), and Lojshová (2003) use total factor productivity as a productivity proxy, while due to the lack of data on TFP many others, such as Coricelli and Jazbec (2004), Žumer (2002), use average productivity of labour. Comparing the total factor productivity and average productivity of labour, the argument against the usage of the average productivity of labour is that it is not entirely clear, if the average labour productivity should be regarded as a reliable indicator of a sustainable productivity growth, which has a long-term effect on the economy (De Gregorio and Wolf, 1994). However, according to Canzoneri, Cumby and Diba (1999) the argument against the TFP is that the TFP could be a result of a possibly unreliable data collection of sectoral capital stocks comparing to the data collection of sectoral employment and sectoral gross value added, especially in the case of the shorter-term series. Sargent and Rodriguez (2000) also concluded that if the intent of the research is to examine trends in the economy over a period of less than a decade or so, labour productivity would be a better measure than the TFP. According to Kovács (2002), another setback of using TFP is that, during the catch-up faze the capital accumulation intensifies faster in the transition/accession countries than in the developed countries, due to the lower starting point in macroeconomic fundamentals of transition/accession countries. Therefore, the HBS effect might be overestimated in this case. Listing some of the arguments against the usage of the TFP, we rather include the average labour productivity as a productivity proxy in the model.

Comparing to the vast HBS literature in the 2000s in the accession process of the countries to the EU and the monetary union, less theoretical work was done concerning the HBS effect in structural and more complex models. Rogoff (1992) was the first to implement a

general equilibrium framework, with which the demand side of the economy within the HBS theory was introduced. This opened new possibilities for further investigation of relative productivity effects of production factors and the effects of the demand side of the economy on price levels. For instance, Mihaljek and Klau (2002) concluded that the HBS effect could have important policy implications for the EU accession countries in order to satisfy the Maastricht inflation criterion. Investigating Mihaljek's point, Masten (2008) constructed a two-sector DSGE model whether the HBS effect could represent an issue in satisfying the Maastricht inflation criterion. Natalucci and Ravenna (2002) compared the magnitude of the HBS effect within different exchange rate regimes in the general equilibrium model, while Restout (2009) allowed for varying mark-ups in its general equilibrium framework. However, Asea and Mendoza (1994) concluded that the proof of the HBS theory within a general equilibrium framework cannot reliably assess the relationship between output per capita and domestic relative prices. In other words, conclusions regarding the HBS theory from cross-country analyses can only be conditionally accepted since it is difficult to account for cross-country trend deviations from purchasing power parity (PPP). Even more, Bergin, Glick and Taylor (2004) showed that the relationship between output per capita and domestic relative prices had historically oscillated too much in order to provide sufficient evidence for the existence of the HBS theory by cross-section empirical studies. They suggest that the HBS theory should be tested within-sector analysis.

Following the general equilibrium strand of the HBS related literature, Rabanal (2009) offers three explanations for studying sectoral inflation dynamics in Spain in a DSGE model structure. The first explanation relates to the role of productivity growth differentials, which directly brings the possibility to study the HBS effect. Altissimo et al. (2005) introduced a seminal paper on the productivity growth differentials in the DSGE model setting. The second explanation adds to the role of the demand-side effects in shaping the inflation dynamics (López-Salido et al., 2005). The third explanation suggests that, due to the different product and labor market structures, there is heterogeneity of the inflation dynamics processes in each country of the union (Angeloni and Ehrmann, 2007; Andrés et al., 2003). Rabanal (2009) concludes that even when economies are hit by symmetric external shocks such as for example oil prices, world demand, or nominal exchange rate, the response of sectoral inflation will be different across countries. The Rabanal's model was adopted by Micaleff and Cyrus (2013) as well. They analyse the relative importance of the three main determinants of inflation differentials in Malta. Based on these considerations, we present the structured theoretical framework in the following section.

### **3. Model**

In this section, we present the theoretical framework of the two-country two-sector DGSE model. The DSGE framework follows the Rabanal (2009) model, but the main contribution of the theoretical model is the extension for sectoral wage rigidities, thus making the model more realistic. Additionally we introduce an augmented technology process with quality improvement (Masten, 2008). In order to investigate the HBS effect phenomenon, different sectoral productivity shocks have to be introduced, providing asymmetry between sectors. The monetary union is made of two economies; the domestic and foreign country with a common monetary policy rule. They are indexed on intervals  $[0, s]$  and  $[s, 1]$ , respectively, where  $s$  denotes the size of the domestic country with respect to two-country universe. In our case, we relate to Slovenia and the rest of the euro area. The following

section only gives a structural domestic economy description, since the foreign economy block is analogous to the domestic economy, which is our case Slovenia.

### 3.1 Households

The assumption is that the representative household maximizes its utility function, given by

$$E_0 \sum_{t=0}^{\infty} \beta^t = \left[ \ln(C_t(i) - hC_{t-1}(i)) - \frac{L_t(i)^{1+\varpi}}{1+\varpi} \right] \quad (1)$$

where  $C_t(i)$  and  $L_t(i)$  represent consumption and quantity of work effort of a particular household. The parameter  $0 < \beta < 1$  is the discount factor of household. We assume that households value the current consumption more than the future one. The parameter  $0 < \varpi < \infty$  is the inverse of the elasticity of work effort with respect to the real wage (Frisch elasticity parameter). We assume the consumption habits as well, which is represented by the parameter  $0 < h < 1$ .

The consumption index  $C_t(i)$  is defined by the constant elasticity of substitution (CES) function between tradable and non-tradable goods and holds for all households, so that  $C_t(i) = C_t^3$

$$C_t = \left[ (\omega_{TN})^{\frac{1}{\nu_{TN}}} (C_t^T)^{\frac{\nu_{TN}-1}{\nu_{TN}}} + (1 - \omega_{TN})^{\frac{1}{\nu_{TN}}} (C_t^N)^{\frac{\nu_{TN}-1}{\nu_{TN}}} \right]^{\frac{\nu_{TN}}{\nu_{TN}-1}} \quad (2)$$

where the parameter  $\omega_{TN}$  represents the share of the tradable goods in the aggregate consumption basket. The parameter  $\nu_{TN} > 1$  represents the elasticity of substitution between the tradable and non-tradable goods.

Since the demand for tradable goods is not dependent only on domestic goods, but foreign as well, the index of the tradable consumption good is written analogously to the equation (3) with which the aggregate consumption index is defined

$$C_t^T = \left[ (\omega_{HF})^{\frac{1}{\nu_{HF}}} (C_t^H)^{\frac{\nu_{HF}-1}{\nu_{HF}}} + (1 - \omega_{HF})^{\frac{1}{\nu_{HF}}} (C_t^F)^{\frac{\nu_{HF}-1}{\nu_{HF}}} \right]^{\frac{\nu_{HF}}{\nu_{HF}-1}} \quad (3)$$

where  $\omega_{HF}$  represents the share of domestic tradable goods in the tradable consumption basket. The parameter  $\nu_{HF} > 1$  is therefore the elasticity of substitution between the domestic tradable goods and tradable goods produced abroad.

The indexes of individual goods are defined by the following equations, and represent a continuum of differenced goods of the same type

$$C_t^H \equiv \left[ \int_0^S c_t^H(h)^{\frac{\nu-1}{\nu}} dh \right]^{\frac{\nu}{\nu-1}} \quad (4)$$

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<sup>3</sup> We scale the variables in the model with  $Z_t^C = (Z_t^T)^{\omega_{TN}} (Z_t^N)^{(1-\omega_{TN})}$  so that the variables enter the model detrended, for example.  $C_t = \check{C}_t / Z_t^C$ . The scaling variable  $Z_t^C$  ensures a constant steady-state level of utility and is determined by productivity dynamics (Masten, 2008).

$$C_t^F \equiv \left[ \int_s^1 c_t^F(f)^{\frac{\nu-1}{\nu}} df \right]^{\frac{\nu}{\nu-1}} \quad (5)$$

and

$$C_t^N \equiv \left[ \int_0^s c_t^N(n)^{\frac{\nu-1}{\nu}} dn \right]^{\frac{\nu}{\nu-1}} \quad (6)$$

The parameter  $\nu > 1$  denotes the elasticity of substitution within one type of differentiated good:  $c_t^H$ ,  $c_t^F$  and  $c_t^N$ . The same principle can be applied to price indexes. The aggregate price index,  $P_t$ , is then given by

$$P_t = [\omega_{TN}(P_t^T)^{1-\nu_{TN}} + (1 - \omega_{TN})(P_t^N)^{1-\nu_{TN}}]^{\frac{1}{1-\nu_{TN}}} \quad (7)$$

As above, the price index for tradable goods is given by

$$P_t^T = [\omega_{HF}(P_t^H)^{1-\nu_{HF}} + (1 - \omega_{HF})(P_t^F)^{1-\nu_{HF}}]^{\frac{1}{1-\nu_{HF}}} \quad (8)$$

Households have a set of contingent riskless euro area bonds,  $B_t^{EA}$ , at their disposal that pay one unit of currency in every possible state of nature in  $t + 1$ . The assumption is that households can trade these bonds that pay a gross interest rate of  $R_t^{EA}$ . Since households are *ex ante* identical they face the same budget constraint in each period:

$$\frac{B_t^{EA}}{P_t Z_t R_t^{EA}} \leq \frac{B_{t-1}^{EA}}{Z_{t-1} P_t} + W_t L_t - C_t + \zeta_t \quad (9)$$

where  $W_t$  represents the real wage, while  $\zeta_t$  represents the other income sources of households. As was shown in Chari, Kehoe and McGrattan (2002), the real exchange rate is given by

$$RER_t = \frac{P_t^*}{P_t} = \frac{\mu_t^*}{\mu_t} \quad (10)$$

where the variables  $\mu_t$  and  $\mu_t^*$  represent the marginal utilities of domestic and foreign consumption, respectively.

Labour market is, in comparison to the Rabanal (2009) model, differentiated, thus provides a more realistic model assumption. Further on, the aggregation of work effort of both sectors (i.e. tradable and non-tradable) holds

$$L_t = L_t^T + L_t^N \quad (11)$$

Against this backdrop, each household working in the tradable or non-tradable sector sets its own wage (Erceg et al., 2000; Christiano et al., 2005). Firms aggregate the differentiated supply of labour by transforming it into a homogenous input of labour  $L_t^j$ , where  $j = N, T$ , accordingly to the Dixit-Stiglitz (1977) aggregator



$$L_t^j = \left[ \int_0^1 L_t^j(i)^{\frac{\nu_{L,j}-1}{\nu_{L,j}}} di \right]^{\frac{\nu_{L,j}}{\nu_{L,j}-1}} \quad (12)$$

The parameter  $\nu_{L,j}$  is defined as the wage elasticity within different varieties of labour services in a particular sector, where  $j = N, T$ . Based on that the labour demand function for a particular is given by

$$L_t^j(i) = \left[ \frac{W_t^j(i)}{W_t^j} \right]^{-\nu_{L,j}} L_t^j \quad (13)$$

Combining the equations (12) and (13) we get the aggregate wage, which is obtained from differentiated labour

$$W_t^j = \left[ \int_0^1 W_t^j(i)^{1-\nu_{L,j}} di \right]^{\frac{1}{1-\nu_{L,j}}} \quad (14)$$

In order to introduce the wage frictions in the model, we apply the Calvo (1983) principle. Each household has the monopolistic power over the setting of its wage,  $W_t^j(i)$ , where  $j = N, T$ . Yet not all the households can set their optimal wage at any point of time, but only fraction of households,  $(1 - \alpha_{L,j})$ , where the Calvo parameter is defined on an interval  $0 < \alpha_{L,j} < 1$ . The other part of households,  $\alpha_{L,j}$ , indexate their wage according to the inflation target and the current inflation. The wage inflation of a non-optimizing household is then given by

$$W_{t+k}^j(i) = \prod_{n=1}^k \left( \frac{P_{t+n-1}}{P_{t-1}} \right)^{\varphi_{L,j}} \Pi^{1-\varphi_{L,j}} W_t^j(i) \quad (15)$$

where the parameter  $0 < \varphi_{L,j} < 1$  stands for the degree of wage indexation with respect to target inflation and current inflation, where  $j = N, T$ .

When reoptimizing their wage in period  $t$ , workers of a particular sector choose an optimal wage  $W_t^{j,opt}$  in order to maximize household utility as opposed to their individual utility, where  $j = N, T$ . The utility is subject to a sequence of iso-elastic demand schedules for their labour type, and the usual sequence of household flow budget constraints. The first order condition associated with that problem can be written as

$$\begin{aligned} & E_t \sum_{k=0}^{\infty} (\alpha_{L,j})^k \Lambda_{t,t+k} \\ & \times \left[ \left( \frac{W_t^{j,opt} \left( \frac{P_{t+k-1}}{P_{t-1}} \right)^{\varphi_{L,j}} \Pi^{k(1-\varphi_{L,j})} - (C_{t+k} - hC_{t+k-1}) (L_{t+k}^j(i))^{\bar{\omega}}}{P_{t+k}} \right) L_{t+k}^j(i) \right] \end{aligned} \quad (16)$$

where the expression  $\Lambda_{t,t+k} = \beta^k \lambda_{t+k} / \lambda_t$  represents the stochastic discount factor. The wage dynamics should therefore be

$$W_t^j \equiv \left[ \alpha_{L,j} \left( W_{t-1}^j (\Pi_{t-1})^{\varphi_{L,j}} (\Pi_j)^{1-\varphi_{L,j}} \right)^{1-\nu_{L,j}} + (1 - \alpha_{L,j}) (W_t^{j,opt})^{1-\nu_{L,j}} \right]^{\frac{1}{1-\nu_{L,j}}} \quad (17)$$

where  $j = N, T$ . The average wage on an economy scale is then given by  $W_t = (W_t^T)^{\omega_{TN}} (W_t^N)^{1-\omega_{TN}}$ .

### 3.2 Firms

On the supply side, there are three types of firms, producing two types of tradable goods (indexed by  $H, H^*$ ) and domestic non-tradable goods (indexed by  $N$ ). Each type of firm is facing price rigidities (Calvo, 1983). That means that only a fraction of firms,  $(1 - \alpha_i)$ , where  $i = N, H, H^*$ , can set their optimal price. Other firms,  $\alpha_i$ , where  $i = N, H, H^*$ , index their prices according to the inflation target and current inflation based on the parameter  $0 < \varphi_i < 1$ , where  $i = N, H, H^*$ , that stands for the degree of price indexation with respect to target inflation and current inflation.

Domestic and foreign economies are facing the same deterministic technology process, providing a case for output growth. This means that all the real variables entering the model are non-stationary in levels, but stationary in first differences.

#### Tradable sector

In the tradable sector there are two types of firms. One type of firm produces tradable good for the domestic market and tries to satisfy domestic consumption of tradable goods,  $C_t^H$ . The other type of firm produces tradable good meant for export and tries to satisfy the foreign consumption of domestic goods,  $C_t^{H,*}$ . Each firm in the tradable sector follows the Cobb-Douglas production function, where work effort is the only production factor

$$y_t^H(h) = A_t^T L_t^{T,H}(h) \quad (18)$$

and

$$y_t^{H,*}(f) = A_t^T L_t^{T,H,*}(f) \quad (19)$$

Variable  $A_t^T$  is a sector-specific productivity process that is characterised by quality improvement of higher-quality goods in the tradable sector index  $\chi_t = (Z_t^T)^{\theta_Z}$  with quality improvement parameter  $\theta_Z > 0$  (Masten, 2008), so that

$$\ln A_t^T = \ln Z_t^T - \ln \chi_t \quad (20)$$

The variable  $\chi_t$  represents a quality improvement of goods index that influences wages and marginal costs *via* positive productivity shocks. Masten (2008) finds that the problem of permanent tradable productivity improvement in a typical open economy specification reduces the relative price of domestic tradable goods relative to the foreign ones, thus worsens the terms of trade. Consequently, the real exchange does not appreciate and is not consistent with the empirical evidence found in new European Union member states. On the other hand, introducing quality improvement of higher-quality goods may require the usage of more advanced inputs in the production process and will consequently increase

the marginal costs and product prices. Sallekaris and Vijselaar (2004) introduce a similar mechanism, as they adjust capital with a simple quality correction mechanism<sup>4</sup>.

Variable  $Z_t^T$  represents a tradable sector productivity shock, which is country-specific

$$\ln Z_t^T = \rho_{Z,T} \ln Z_{t-1}^T + \varepsilon_t^Z + \varepsilon_t^{Z,T} \quad (21)$$

We assume that productivity shocks of both sectors can be different and that their growth rates could be different. We let the tradable productivity process  $Z_t^T$  to be affected by two different productivity innovations,  $\varepsilon_t^{Z,T}$ , which is country and sector specific, and  $\varepsilon_t^Z$ , which represents a euro-area wide innovation. For the labour supply it holds  $L_t^T = L_t^{T,H} + L_t^{T,H,*}$ .

Tradable sector firms producing domestic good for the domestic market maximize their profits according to

$$E_t \sum_{k=0}^{\infty} \alpha_H^k \Lambda_{t,t+k} \left[ \frac{P_t^{H,opt}(h) \left( \frac{P_{t+k-1}^H}{P_{t-1}^H} \right)^{\varphi_H} (\Pi_H)^{k(1-\varphi_H)} - MC_{t+k}^T}{P_{t+k}} y_{t+k}^{H,d}(h) \right] \quad (22)$$

subject to

$$y_{t+k}^{H,d}(h) = \left[ \frac{P_t^{H,opt}(h) \left( \frac{P_{t+k-1}^H}{P_{t-1}^H} \right)^{\varphi_H} (\Pi_H)^{k(1-\varphi_H)}}{P_{t+k}^H} \right]^{-\nu} Y_{t+k}^H \quad (23)$$

where the expression  $\Lambda_{t,t+k} = \beta^k \lambda_{t+k} / \lambda_t$  represents the stochastic discount factor, and  $y_{t+k}^{H,d}(h)$  is the tradable good demand of a firm in time  $t+k$ .  $Y_t^H$  is the aggregate domestic-made tradable good demand.

Similarly we can write the maximization profit function for tradable sector firms producing domestic good for the foreign market

$$E_t \sum_{k=0}^{\infty} \alpha_{H,*}^k \Lambda_{t,t+k} \left[ \frac{P_t^{H,*,opt}(f) \left( \frac{P_{t+k-1}^{H,*}}{P_{t-1}^{H,*}} \right)^{\varphi_{H,*}} (\Pi_F)^{k(1-\varphi_{H,*})} - MC_{t+k}^T}{P_{t+k}} y_{t+k}^{H,*,d}(f) \right] \quad (24)$$

subject to

$$y_{t+k}^{H,*,d}(f) = \left[ \frac{P_t^{H,*,opt}(f) \left( \frac{P_{t+k-1}^{H,*}}{P_{t-1}^{H,*}} \right)^{\varphi_{H,*}} (\Pi_{H,*})^{k(1-\varphi_{H,*})}}{P_{t+k}^{H,*}} \right]^{-\nu} Y_{t+k}^{H,*} \quad (25)$$

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<sup>4</sup> The idea of adjusting prices with quality improvements goes back into the 90-ies, as the study of Gordon (1990) tried to empirically document these biases. Later research focused on constructing quality-adjusted price indexes (Hulten, 1992; Greenwood et al., 1997; Cummins and Violante, 2002), production based estimates (Bahk and Gort, 1993) and capital model (Hobijn, 2000).

where the expression  $\Lambda_{t,t+k} = \beta^k \lambda_{t+k}/\lambda_t$  represents the stochastic discount factor, and  $y_{t+k}^{H,*d}(h)$  is the tradable good demand of a firm in time  $t+k$ .  $Y_t^{H,*}$  is the aggregate domestic tradable good demand from abroad.

Real marginal costs in the tradable sector for both types of firms are defined as  $MC_t^T$ . Marginal costs are defined as (the real wage is normalized for augmented productivity)

$$MC_t^T = \frac{w_t^T}{A_t^T} \quad (26)$$

Both types of tradable sector firms maximize their profit with respect to prices  $p_t^H(h)$  and  $p_t^{H,*}(f)$  and demands  $y_{t+k}^{H,d}(h)$  and  $y_{t+k}^{H,*d}(f)$ , respectively. The tradable price dynamics of the domestic produced good for the domestic market is

$$P_t^H \equiv \left[ \alpha_H (P_{t-1}^H (\Pi_{t-1}^H)^{\varphi_H} (\Pi_H)^{1-\varphi_H})^{1-\nu} + (1 - \alpha_H) (P_t^{H,opt})^{1-\nu} \right]^{\frac{1}{1-\nu}} \quad (27)$$

where the  $P_t^{H,opt}$  is the optimal price and  $\Pi_{t-1}^H = P_{t-1}^H/P_{t-2}^H$ . The tradable price dynamics of the domestic good for the foreign market is

$$P_t^{H,*} \equiv \left[ \alpha_{H,*} \left( P_{t-1}^{H,*} (\Pi_{t-1}^{H,*})^{\varphi_{H,*}} (\Pi_{H,*})^{1-\varphi_{H,*}} \right)^{1-\nu} + (1 - \alpha_{H,*}) (P_t^{H,*opt})^{1-\nu} \right]^{\frac{1}{1-\nu}} \quad (28)$$

where the  $P_t^{H,*opt}$  is the optimal price and  $\Pi_{t-1}^{H,*} = P_{t-1}^{H,*}/P_{t-2}^{H,*}$ .

### Non-tradable sector

Analogously to the tradable sector, each non-tradable sector firm follows Cobb-Douglas production function, where work effort is the only production factor

$$y_t^N(n) = A_t^N L_t^N(n) \quad (29)$$

Variable  $A_t^N$  is a sector-specific productivity process that is characterised by the quality improvement index  $\chi_t = (Z_t^T)^{\theta_Z}$  so that

$$\ln A_t^N = \ln Z_t^N - \ln \chi_t \quad (30)$$

In this respect, we assume that the sector-specific productivity process  $A_t^N$  is affected by the quality improvement of goods  $\chi_t$  in the tradable sector, while the variable  $Z_t^N$  represents a non-tradable sector productivity shock, which is again country-specific

$$\ln Z_t^N = \rho_{Z,N} \ln Z_{t-1}^N + \varepsilon_t^{Z,N} \quad (31)$$

where we let the non-tradable productivity process  $Z_t^N$  to be affected by a sector-specific innovation,  $\varepsilon_t^{Z,N}$ .

Non-tradable sector firms maximize their profits

$$E_t \sum_{k=0}^{\infty} \alpha_N^k \Lambda_{t,t+k} \left[ \frac{P_t^{N,opt}(n) \left( \frac{P_{t+k}^N}{P_{t-1}^N} \right)^{\varphi_N} (\Pi_N)^{k(1-\varphi_N)} - MC_{t+k}^N}{P_{t+k}} y_{t+k}^{N,d}(n) \right] \quad (32)$$

subject to

$$y_{t+k}^{N,d}(n) = \left[ \frac{P_t^{N,opt}(n)}{P_{t+k}^N} \left( \frac{P_{t+k}^N}{P_{t-1}^N} \right)^{\varphi_N} (\Pi_N)^{k(1-\varphi_N)} \right]^{-\nu} Y_{t+k}^N \quad (33)$$

where the expression  $\Lambda_{t,t+k} = \beta^k \lambda_{t+k}/\lambda_t$  represents the stochastic discount factor, and  $y_{t+k}^{N,d}(n)$  is the non-tradable good demand of a firm in time  $t+k$ .  $Y_t^N$  is the aggregate non-tradable good demand. Real marginal costs in the non-tradable sector are defined as  $MC_t^N$ . From the cost-optimization perspective, the marginal costs are defined as (the real wage is normalized for productivity)

$$MC_t^N = \frac{W_t^N}{A_t^N} \quad (34)$$

A non-tradable sector firm maximizes its profit with respect to price  $p_t^N(n)$  and demand  $y_{t+k}^{N,d}(n)$ . The non-tradable price dynamics should therefore be

$$P_t^N \equiv \left[ \alpha_N (P_{t-1}^N (\Pi_{t-1}^N)^{\varphi_N} (\Pi_N)^{1-\varphi_N})^{1-\nu} + (1-\alpha_N) (P_t^{N,opt})^{1-\nu} \right]^{\frac{1}{1-\nu}} \quad (35)$$

where the  $P_t^{N,opt}$  is the optimal price and  $\Pi_{t-1}^N = P_{t-1}^N/P_{t-2}^N$ .

### 3.3 Monetary policy

Monetary policy is modelled as a Taylor rule (Taylor, 1993) and is the same for both economies

$$R_t^{EA} = \bar{R}^{1-\varrho_r} (R_{t-1}^{EA})^{\varrho_r} \left( \frac{\Pi_t^{EA}}{\bar{\Pi}} \right)^{(1-\varrho_r)\gamma_\pi} \left( \frac{Y_t^{EA}}{\bar{Y}} \right)^{(1-\varrho_r)\gamma_y} e^{\varepsilon_t^{MP}} \quad (36)$$

where  $\varepsilon_t^{MP}$  represents the monetary policy shock, while the interest rate  $R_t^{EA}$  responds to inflation and output gaps. The total output of the euro area is defined by  $Y_t^{EA} = (Y_t)^s (Y_t^*)^{1-s}$ , while the overall inflation in the euro area is defined by  $\Pi_t^{EA} = (\Pi_t)^s (\Pi_t^*)^{1-s}$ , where  $s$  is the size of the domestic country. The parameter  $\varrho_r$  is the weight parameter for the responsiveness of the past interest rate, while  $\gamma_\pi$  and  $\gamma_y$  are Taylor type parameters for the response of the interest rate accordingly to both gaps.

### 3.4 Market clearing

The clearing conditions are

$$Y_t^T = C_t^H + C_t^{H,*} + G_t^T \quad (37)$$

and

$$Y_t^N = C_t^N + G_t^N \quad (38)$$

where variables  $G_t^T$  and  $G_t^N$  represent exogenous government spending shocks. Combining the equations (37) and (38) the real GDP is

$$Y_t = \frac{P_t^T}{P_t} Y_t^T + \frac{P_t^N}{P_t} Y_t^N \quad (39)$$

What is left to do is to define the government sectoral spending process

$$\ln G_t^i = \rho_{G,i} \ln G_{t-1}^i + \varepsilon_t^{G,i} \quad (40)$$

where for  $i = N, T$ .

## 4. Tradability of sectors and data

As the theoretical model is divided into a tradable and non-tradable sector some attention is needed for the specification and the sectoral definition of the data. The dataset consists of quarterly Slovene and euro area sectoral data, which is available at the Eurostat<sup>5</sup>. The time series data spans from 1998Q4 to 2018Q1 and includes sectoral gross value added data and sectoral price indexes data.

### 4.1 Tradability of sectors

To begin with, the tradability of the sectors has to be defined. Officer (1976) proposed the following division of sectors. Manufacturing and other industry activities belong in a tradable sector, while the services represent the non-tradable sector. De Gregorio et al. (1994) later on used a ratio of exports to total production to define both sectors. Their division threshold is set to 10 percent, stating that the sector is defined as tradable, if the ratio of exports exceeds the 10 percent threshold, and the sector is defined as non-tradable, if the ratio of exports does not exceed the 10 percent threshold. Following the De Gregorio et al. (1994) sectoral division, we take a step further by strictly distinguish between the tradable and non-tradable sector. This means that we exclude those activities from the analysis that oscillate around the 10 percent threshold too much. We provide a more detailed specification below.

First, data on the share of exports in total value added have to be extracted from the input-output tables available at the World Input-Output Database (WIOD). We use a standard ISIC/NACE Revision 2 aggregation category, which is used for reporting data from the

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<sup>5</sup> Available at the European Commission's statistical database site <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>

System of National Accounts (SNA) for a wide range of countries. We present a 10-sector breakdown in the Table 1.

Table 1. NACE Revision 2 10-sector classification of economic activities

NACE Revision 2	Sector description	Ratio of exports (in %)	Tradability
A	Agriculture, forestry and fishing	18.32*	
B, C, D, E	Manufacturing, mining and quarrying and other industry	45.99	T
F	Construction	2.20	N
G, H, I	Wholesale and retail trade, transportation and storage, accommodation and food services	17.25	T
J	Information and communication	10.42	
K	Financial and insurance activities	12.63	
L	Real estate activities	0.56	N
M, N	Professional, scientific, technical, administrative and support services	16.39**	
O, P, Q	Public administration, defence, education, human health and social work services	0.95	N
R, S, T, U	Other services	6.27	N

*Source:* European commission, author's calculations.

\*Note: Countries such as Belgium, Netherlands and Luxembourg stand out with their ratio-of-export figures thus driving up the average of ratio of exports in the agriculture sector.

\*\*Note: Countries such as Ireland, Netherlands and Luxembourg stand out with their ratio-of-export figures thus driving up the average of ratio of exports in the professional services sector.

As mentioned above, to divide the 10 sectors into tradable and non-tradable sectors, we use a similar approach as De Gregorio et al. (1994). However, in the present paper we put emphasis merely only on strictly tradable and non-tradable sector, meaning that we exclude those sectors from the analysis, which are not distinctively tradable or non-tradable. A sector is then treated as tradable if its ratio of exports exceeds the 10 percent threshold for at least 75 percent of time using the WIOD data in the 2000-2011 period. The same principle is applied for the definition of a non-tradable sector. A sector is treated as non-tradable if its ratio of exports is under the 10 percent threshold for at least 75 percent of time using the WIOD data and the timespan from 2000 until 2011. Applying stricter conditions regarding the division of sector means that NACE Rev. 2 sectors such as agriculture, forestry and fishing (A), information and communication (J), financial and insurance activities (K), professional, scientific, technical, administration and support services (M and N) are excluded from the analysis. These excluded sectors account for around 20 percent in total value added. Based on this threshold the manufacturing, mining, quarrying and other industry (B, C, D and E), wholesale, retail, transportation, storage, accommodation and food services (G, H and I) are treated as tradable sectors, while construction (F), real estate activities (L), public administration, defence, education, human health, and social work services (O, P and Q), and other services (R, S, T and U) are treated as non-tradable sectors.

## 4.2 Sectoral inflation and productivity

Based on the quarterly data available from the Eurostat and the consideration of the classification of economic activities into a tradable and non-tradable sector (as defined in Table 1) supported by time-varying sectoral gross value added weights expressed in millions of euros in 2015, growth rates in prices for the tradable and non-tradable sectors are obtained. We use the same principle that was applied to divide economic activities into tradable and non-tradable sectors to divide sectoral growth rate of value added for both sectors, based on the aggregation done for sectoral inflation. This way we get the growth rates for the output on a quarterly frequency basis for a separate sector, i.e. tradable and non-tradable.

## 4.3 Data entering the model

After defining and obtaining the sectoral data, we can provide a full description of the dataset entering the model in table 2. There are 9 observable variables at a quarterly frequency in the period of 1998Q4-2018Q1. Tradable sector figures stand out the most and have the highest variability. Intuitively, this means that the tradable sector is more responsive to changes in different phases of business cycles. Additionally, Slovene data in comparison to the euro area data varies more, thus providing a case that small open economies are more vulnerable to macroeconomic imbalances.

Table 2. Descriptive statistics (in p.p. deviations from the steady state)

Variable description	Data transformation	Country	Minimum	Maximum	Standard deviation
<b>Weighted tradable sector inflation</b>	demeaned log-differences	SI	-2.31	2.28	0.93
<b>Weighted tradable sector inflation</b>	demeaned log-differences	EA	-1.08	1.32	0.39
<b>Weighted tradable sector gross value added</b>	demeaned log-differences	SI	-9.95	3.16	1.71
<b>Weighted tradable sector gross value added</b>	demeaned log-differences	EA	-5.62	2.65	1.08
<b>Weighted non-tradable sector inflation</b>	demeaned log-differences	SI	-1.36	2.45	0.77
<b>Weighted non-tradable sector inflation</b>	demeaned log-differences	EA	-0.68	0.91	0.36
<b>Weighted non-tradable sector gross value added</b>	demeaned log-differences	SI	-1.84	2.09	0.70
<b>Weighted non-tradable sector gross value added</b>	demeaned log-differences	EA	-0.47	2.77	0.37
<b>3-month Euribor</b>	Interest rate given by $\log(1 + r_t/400)$ , demeaned log-differences	EA	-0.55	0.78	0.42

Source: Eurostat, author's calculations.



## 5. Calibration of the model

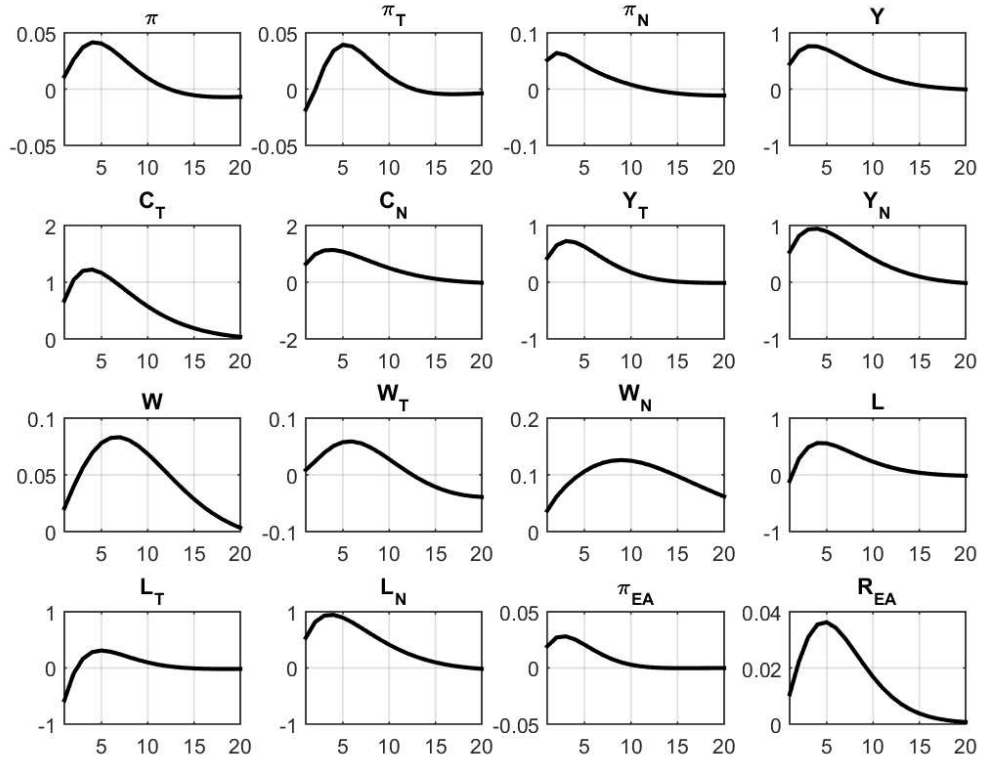
We set the values of the calibrated parameters accordingly to known empirical facts from the existing literature and characteristics of the modelled economies, which are in our case Slovenia and the euro area. The discount factor,  $\beta$ , is set to 0.99 following Smets and Wouters (2003) paper. The degree of habit formation parameter,  $h$ , for Slovenia is set to 0.80 (as in Kilponen et al., 2015), while for the euro area is set to 0.60 (as in Smets and Wouters, 2003), thus making the Slovene consumption slower to respond and more persistent. The Slovene economy size parameter,  $s$ , is set to 0.01.<sup>6</sup> The Frisch elasticity or the inverse of the elasticity of work effort for both economies has a typical parameter value of 2 (Smets and Wouters, 2003; Rabanal, 2009; Rabanal, 2012; Micallef and Cyrus, 2013). The elasticities of substitution between tradable and non-tradable goods for both, domestic ( $v_{TN}$ ) and foreign ( $v_{TN,*}$ ), economies take the value of 0.44, following the values set by Stockman and Tesar (1995). The elasticities of substitution between domestic produced and foreign produced goods for both, domestic ( $v_{HF}$ ) and foreign ( $v_{HF,*}$ ), economies take the value of 1.5, following Chari, Kehoe and McGrattan (2002). Further on, the shares of important economic variables are calibrated as well. The share of government spending relative to GDP in Slovenia is set to 0.17 and for the euro area is set to 0.20, while the average share of tradable goods in the consumption basket is set to 0.58 in Slovenia and 0.61 in the euro area. The Calvo wage parameters for both countries and both sectors are set to 0.75. The price stickiness are set to 0.70 and 0.85 for the tradable and non-tradable sectors respectively, thus closely following the values set for Slovenia in Clancy, Jacquinot and Lozej (2014) and Kilponen et al. (2015). The wage indexation parameters are set to 0.75 according to Rabanal (2012). The quality improvement parameters  $\theta_Z$  and  $\theta_{Z,*}$ , for both economies are set at 0.25. The Taylor rule values inflation and output gap response parameters ( $\gamma_\pi = 1.5$  and  $\gamma_y = 0.1$ ) are set to the usual euro area monetary policy values and are close to Fourçans and Vranceanu (2004) estimated parameters for the euro area.

The calibrated model is able to produce the HBS type of productivity shock. The following figure shows the impulse responses of the main macroeconomic variables to a 1 p.p. domestic tradable sector productivity shock, based on the calibrated model. The productivity shock increases the production of both sectors, the tradable and the non-tradable. As the quality improvement mechanism takes place, firms are compelled to raise wages as more sophisticated labour force is needed as the productivity picks up. The pick-up in wages increases inflation and consumption in both sectors. What is noteworthy is that the non-tradable sector inflation increases more than the tradable sector, thus providing a case for HBS effect.

Figure 1. Impulse responses of the main variables to a 1 p.p. domestic tradable sector productivity shock (deviations from steady state, in p.p.)

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<sup>6</sup> In comparison to the euro area the size of the Slovene economy is even smaller. The reason behind a slightly bigger economy size parameter is that very small numbers of the parameters could represent numerical difficulties for the model. These are shown in a very slow convergence after shocking the model or even in the inability of computing the responses of the shocks. However, 0.01 economy size parameter does not significantly influence the universum of both economies, which would be the case for small open economies.



## 6. Estimation of the model and comparison with the calibrated model

With the obtained dataset and the calibration parameters set the two-country two-sector DSGE model is ready to be estimated. Doing that, we use the Bayesian inference methodology. We set the prior distribution of the estimated parameters, given in Table 3. The prior and the posterior distribution of the estimated parameters and the shocks is presented in the Table 3, while the figures with comparisons between the prior and the posterior distribution of the parameters are presented in Appendix A, while in the Appendix B the dynamics of the exogenous shocks is presented. The Metropolis-Hastings MCMC algorithm is used with 700.000 steps and two sequential chains with the acceptance rate per chain of around 27%.

We estimate the quality improvement parameters  $\theta_z$  and  $\theta_{z,*}$ , for both economies. The priors of both parameters were set at 0.25, while the estimates of both parameters took the values of 0.1750 and 0.2781. The estimation values of both quality improvement parameters are below the calibrated value of the parameter for the domestic economy in Masten (2008). Since Slovenia was catching-up the average of the euro area and experienced higher growth and inflation, the estimate of the quality improvement mechanism had to be stronger during this period. With respect to the other estimated parameters, the shock persistence parameters seem to suggest the productivity persistence parameters show less persistence than the demand shocks entering both non-tradable and tradable sector. The parameter  $\rho_r$  of the monetary policy rule is estimated as well, and takes the value of 0.5352, suggesting a relatively high persistence of the past interest rate.

In comparison to the calibrated model, the price Calvo rigidity parameters ( $\alpha$ 's) are mostly estimated to be higher, meaning that the prices respond slower to exogenous shocks. The values of the Calvo parameters are similar comparing the foreign or domestic economy.

Table 3. Prior and posterior distribution of the estimated parameters and shocks

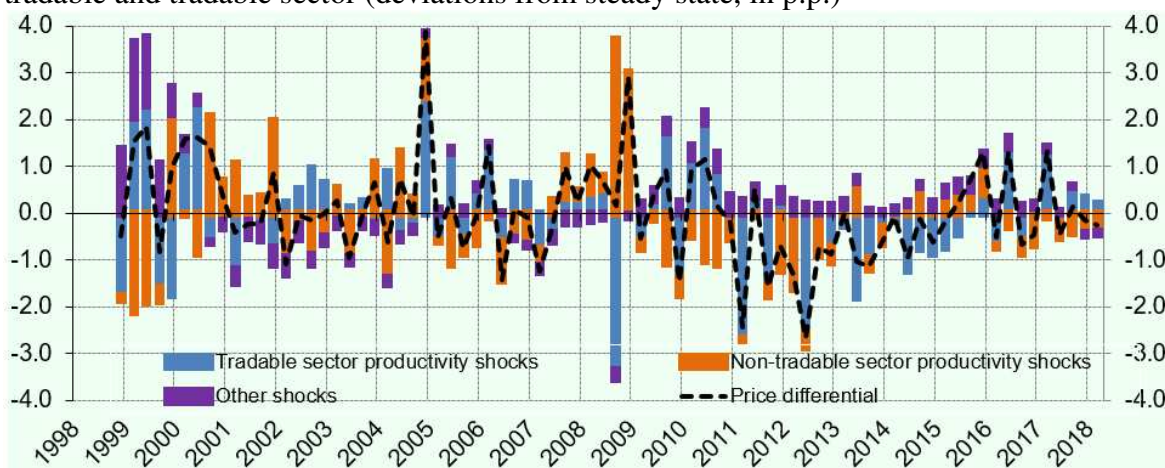
Parameter	Calibration model values	Prior mode	Posterior mode	90% HPD interval		Prior distribution	Prior distribution
$\theta_Z$	0.250	0.250	0.1750	0.1415	0.2083	inv. gamma	0.050
$\theta_{Z,*}$	0.250	0.250	0.2781	0.1944	0.3604	inv. gamma	0.050
$\alpha_H$	0.700	0.810	0.6285	0.6000	0.6588	beta	0.030
$\alpha_F$	0.700	0.750	0.8486	0.8147	0.8825	beta	0.050
$\alpha_{H,*}$	0.700	0.750	0.7776	0.7079	0.8476	beta	0.050
$\alpha_{F,*}$	0.700	0.750	0.8980	0.8818	0.9144	beta	0.050
$\alpha_N$	0.850	0.810	0.8162	0.7974	0.8352	beta	0.030
$\alpha_{N,*}$	0.850	0.750	0.9149	0.8987	0.9313	beta	0.050
$\alpha_{W,T}$	0.800	0.750	0.7948	0.7532	0.8376	beta	0.030
$\alpha_{W,T,*}$	0.750	0.750	0.7749	0.7298	0.8211	beta	0.030
$\alpha_{W,N}$	0.900	0.850	0.8722	0.8470	0.8986	beta	0.020
$\alpha_{W,N,*}$	0.750	0.750	0.7740	0.7288	0.8214	beta	0.030
$\nu_{TN}$	0.440	0.500	0.5489	0.1992	0.8834	gamma	0.200
$\nu_{HF}$	1.500	1.500	1.1513	0.5202	1.7417	gamma	0.500
$\varphi_H$	0.500	0.500	0.1578	0.0284	0.2800	beta	0.200
$\varphi_F$	0.500	0.500	0.5310	0.2786	0.7757	beta	0.200
$\varphi_{H,*}$	0.500	0.500	0.5002	0.3360	0.6634	beta	0.100
$\varphi_{F,*}$	0.500	0.500	0.1249	0.0185	0.2248	beta	0.200
$\varphi_N$	0.500	0.500	0.4509	0.2993	0.5975	beta	0.100
$\varphi_{N,*}$	0.500	0.500	0.2704	0.1469	0.3854	beta	0.100
$\rho_{Z,T}$	0.750	0.750	0.4451	0.3168	0.5763	beta	0.100
$\rho_{Z,T,*}$	0.750	0.750	0.3080	0.1996	0.4152	beta	0.100
$\rho_{Z,N}$	0.750	0.750	0.5893	0.4267	0.7423	beta	0.100
$\rho_{Z,N,*}$	0.750	0.750	0.2773	0.1672	0.3834	beta	0.100
$\rho_{G,T}$	0.750	0.750	0.6869	0.5833	0.7902	beta	0.100
$\rho_{G,T,*}$	0.750	0.750	0.9593	0.9374	0.9820	beta	0.100
$\rho_{G,N}$	0.750	0.750	0.7385	0.6667	0.8132	beta	0.100
$\rho_{G,N,*}$	0.750	0.750	0.8871	0.7975	0.9707	beta	0.100
$\varrho_T$	0.750	0.750	0.5352	0.3889	0.6779	beta	0.100
$\varepsilon_{MP}$	-	0.400	0.1264	0.1106	0.1415	inv. gamma	0.100
$\varepsilon_Z$	-	0.500	0.1785	0.1463	0.2089	inv. gamma	0.200
$\varepsilon_{Z,T}$	-	0.700	0.2573	0.2227	0.2924	inv. gamma	0.200
$\varepsilon_{Z,T,*}$	-	0.500	0.2639	0.1955	0.3296	inv. gamma	0.200
$\varepsilon_{Z,N}$	-	0.700	0.2467	0.2127	0.2797	inv. gamma	0.200
$\varepsilon_{Z,N,*}$	-	0.500	0.2950	0.2034	0.3821	inv. gamma	0.200
$\varepsilon_{G,T}$	-	1.000	0.5532	0.4769	0.6276	inv. gamma	0.200
$\varepsilon_{G,T,*}$	-	1.000	0.4192	0.3673	0.4681	inv. gamma	0.200
$\varepsilon_{G,N}$	-	1.000	0.6805	0.5853	0.7762	inv. gamma	0.200
$\varepsilon_{G,N,*}$	-	1.000	0.4164	0.3643	0.4672	inv. gamma	0.200

Source: author's calculations

## 6.1 Impulse response functions and the historical shock decomposition

In this subsection, we present the historical shock decomposition and the impulse response functions. The purpose of both is to provide a description of the severity of shocks that influence the macroeconomic variables. Figure 1 shows the contributions of the exogenous shocks on the price differential between the non-tradable and tradable sector through time. It is evident, that the inflation differential between the non-tradable and tradable sectors was influenced by productivity components. As the financial crisis lingered on in the second wave after 2010, the difference between the non-tradable and tradable dynamics turned to be negative, implying a slowdown in the tradable sector productivity. Only with the start of the recovery of the Slovene economy in 2015, the difference between the inflation of both sectors returned to positive figures and continues the pattern before the financial crisis in 2008 by being affected with positive tradable sector productivity shocks.

Figure 1. Historical shock decomposition in the inflation differential between the non-tradable and tradable sector (deviations from steady state, in p.p.)



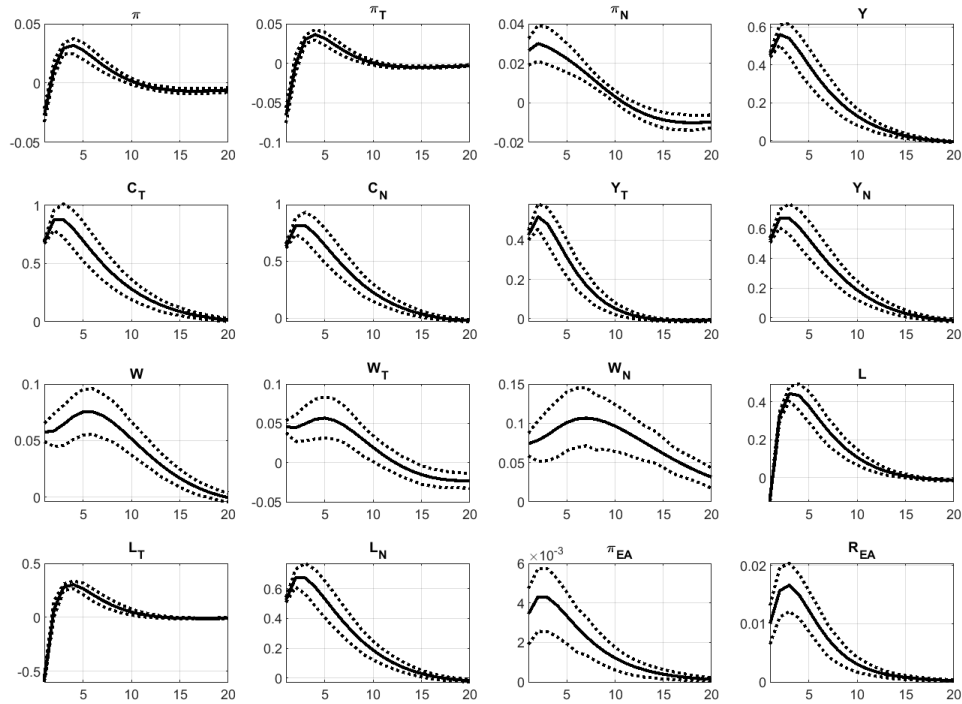
\*Note: Tradable productivity shocks are the sum of the contributions of the country-specific domestic tradable sector shocks  $\varepsilon_{Z,T}$  and  $\varepsilon_{Z,T,*}$  and the common productivity shock  $\varepsilon_Z$ . The non-tradable sector productivity shocks  $\varepsilon_{Z,N}$  and  $\varepsilon_{Z,N,*}$  are depicted as a sum of shock contributions as well. Other shocks are the sum of the contributions of the demand shocks ( $\varepsilon_{G,T}$ ,  $\varepsilon_{G,T,*}$ ,  $\varepsilon_{G,N}$  and  $\varepsilon_{G,N,*}$ ) and the monetary policy shock  $\varepsilon_{MP}$ .

Source: author's calculations.

It is more intuitive to look at the impulse response functions in order to understand the effects of productivity shocks. Figures (2-5) show the responses of the main macroeconomic variables to different exogenous shocks and depict a 20-period horizon. In studying the impulse responses, we will only consider the productivity shocks that hit the two economies. Figure 2 displays the impulse responses of the main variables to a 1 p.p. domestic tradable sector productivity shock,  $\varepsilon_{Z,T}$ . When a positive productivity shock hits the tradable sector, both tradable and non-tradable inflation increase in Slovenia, causing the overall inflation to increase. This is due to a wage increase in the tradable sector *via* quality improvement mechanism that increases the need for more demanding inputs in the production process and thus increasing the marginal costs. As wages increase the marginal costs increase, causing the inflation to increase. The Harrod-Balassa-Samuelson type productivity shock causes the increase of output and consumption as well. Under the implementation of quality improvement mechanism and under the price and wage frictions we provide a baseline model that is able to produce the HBS effect (see the calibration responses). Despite that, based on the Slovene data, we are not completely able to estimate

the HBS effect, since the tradable sector prices increase slightly more than the non-tradable sector prices. The effects on the euro area macroeconomic variables are small.

Figure 2. Impulse responses of the main variables to a 1 p.p. domestic tradable sector productivity shock (deviations from steady state, in p.p.)



The same pattern is observed when we analyse a 1 p.p. common tradable sector technology shock,  $\varepsilon_Z$ , shown in Figure 3. Similar effects happen when a 1 p.p. foreign tradable sector productivity shock,  $\varepsilon_{Z,T,*}$ , hits the rest of the euro area. The difference is that this time the quality mechanism works abroad, so that spillovers come with a lag and in smaller magnitude. As a consequence marginal costs do not increase in the domestic country, but positive effects from the price increase abroad make the tradable sector more profitable, increasing production, consumption, price and wages in the domestic country.

Figure 3. Impulse responses of the main variables to a 1 p.p. common euro area tradable sector productivity shock (deviations from steady state, in p.p.)

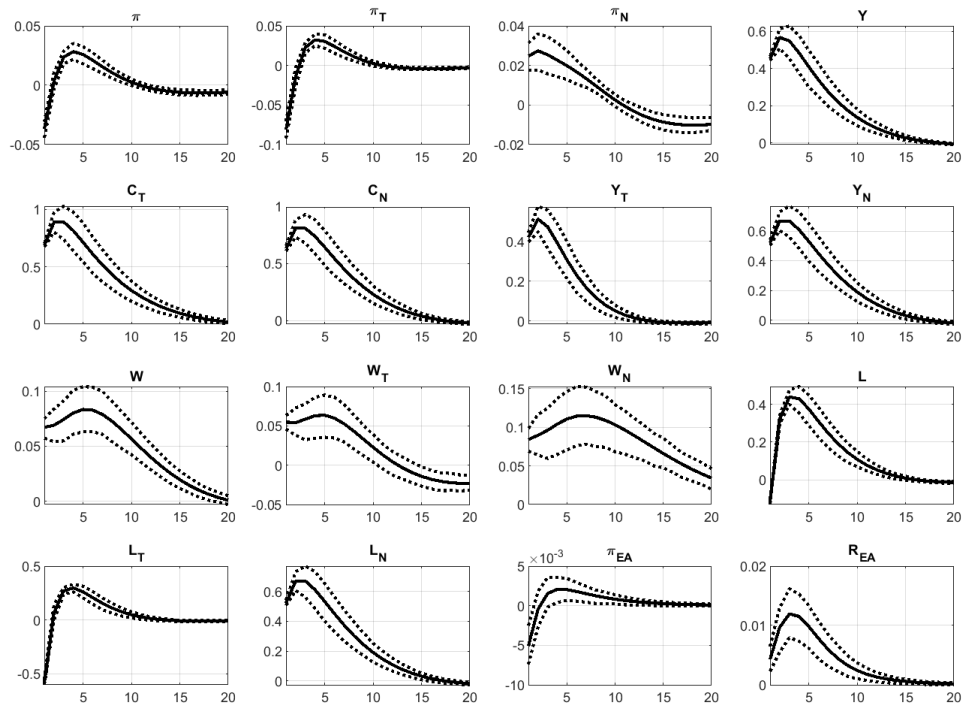
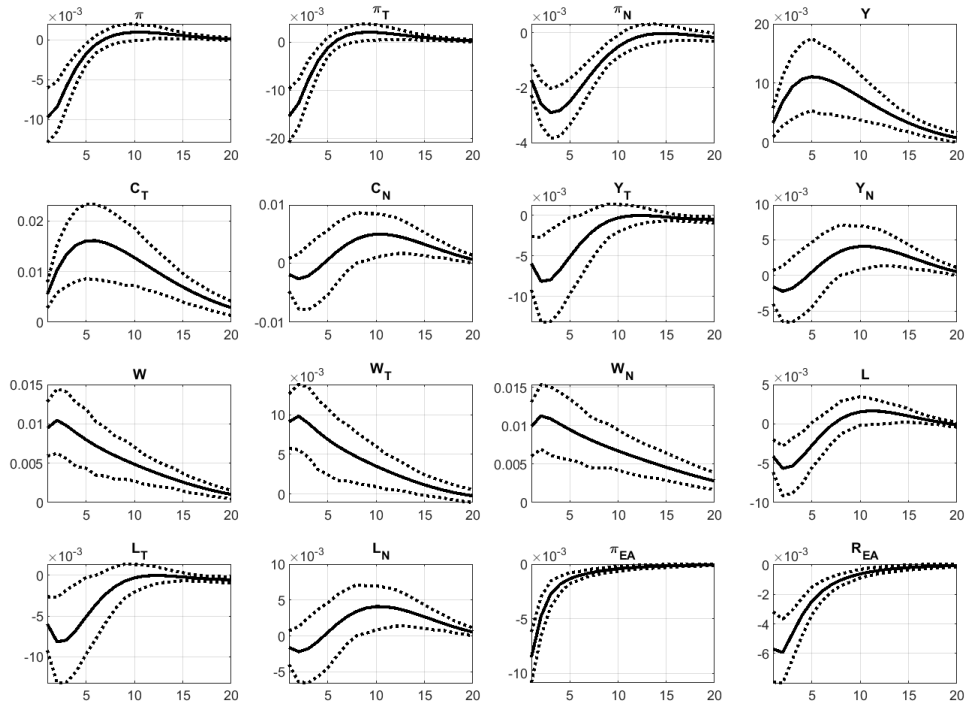
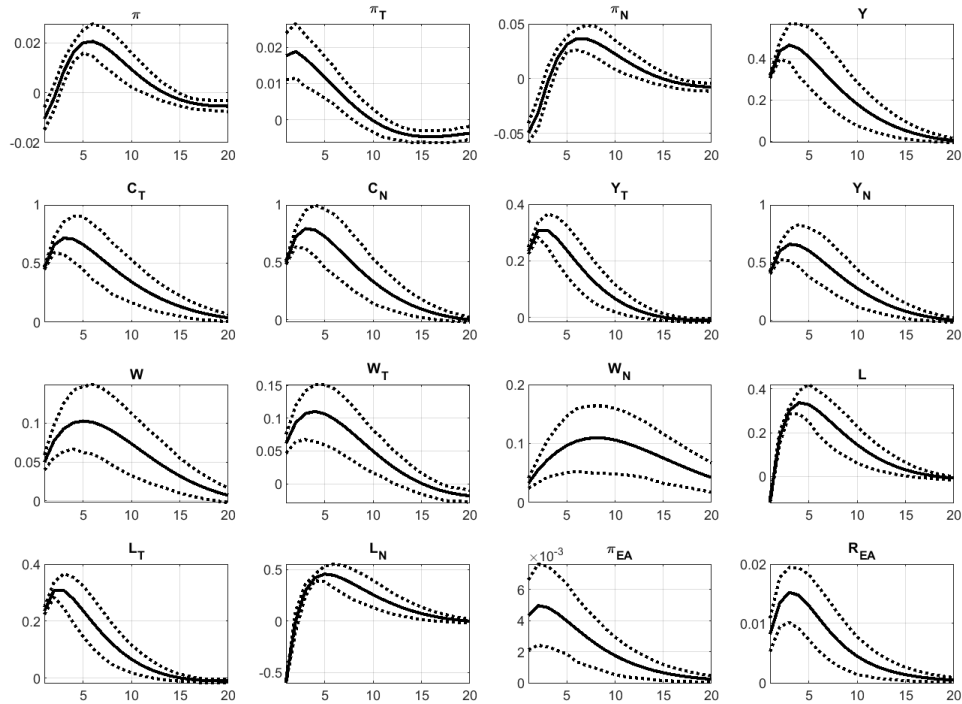


Figure 4. Impulse responses of the main variables to a 1 p.p. foreign tradable sector productivity shock (in p.p. deviations from steady state)



We are left to study the effects of the non-tradable sector productivity shocks, as they are depicted in Figure 5. In contrast to the tradable sector productivity shocks, the domestic non-tradable sector productivity shock,  $\varepsilon_{Z,N}$ , does not enter the quality improvement mechanism. Consequently, it acts more as a (classical productivity) shock that decreases marginal costs, lowers non-tradable sector inflation, while tradable sector marginally increases since the labour supply moves to the tradable sector from the non-tradable sector. The sectoral and the overall output as well as the consumption increase.

Figure 5. Impulse responses of the main variables to a 1 p.p. domestic non-tradable sector productivity shock (deviations from steady state, in p.p.)



## 6.2 Policy implications and way forward

The HBS effect is typically used to explain inflation differentials for those countries experiencing a catching-up process. As the relatively poorer countries adopt new technologies in those sectors that are open to international trade (i.e. the tradable sector), they will experience higher productivity growth in the tradable sector, increased wages *via* quality mechanism, and consequently a higher inflation in sectors that are not open to international trade, as is the nontradable sector. Therefore, the HBS effect hypothesis could help to explain higher inflation rates in the non-tradable sector than in the tradable sector, and hence leading to higher overall inflation.

Another important issue to point out is that the HBS effect theory does not explain the possible sources of productivity differentials between different sectors and countries. As the HBS is often associated with catching-up and convergence phases of less developed countries, it would be possible for a catching-up process to take place without the HBS effect. This happens if productivity growths in both sectors (i.e. the tradable and nontradable sector) are equally high. Additionally, in some countries that already experience high productivity levels may, for various reasons, such as economic policies that are conducive to technological innovation, also experience relatively high productivity growth in the tradable sector. Importantly, structural rigidities and different degrees of competition<sup>7</sup> can affect productivity growth differentials between sectors and overall productivity growth in a way that favours either positive or negative inflation differentials in those countries.

<sup>7</sup> i.e. private vs. public sector.



Despite the wage setting process being typical for the DSGE model setting following Calvo (1983) and later on Christiano (2005) labour market frictions, some issues could still arise in that respect. The wage setting in the non-tradable sector could be in a large extent governed by the non-market forces and other structural rigidities since a large part of the non-tradeable sector is comprised of the public sector. In our case, the model does not structurally distinguish between private and public sectors and that would consequently been able to consider various types of non-market forces. However, it does provide some distinction in a sense of having two different (estimated) rigidity parameters of the wage setting equation for the non-tradable and tradable sector. Based on the estimation figures the non-tradable sector wages seem to be more rigid than in the tradable sector. They are slower to respond to exogenous shocks, which would to some extent simulate the differences between private and public sector. This issue could go beyond the scope of the present paper, but it could represent additional way forward to extend the model into a more complex one by additionally restrict and divide the modelled labour market as well as the government sector.

Nonetheless, the continued process of convergence processes in the euro area should lead to a decline in inflation dispersion amongst the euro area countries due to a price level and income convergence in the long-run. On the other hand, other structural factors such as differences in the degrees of wage and price rigidities and divergent degree of competition in domestic markets may also contributed to the observed inflation differentials and their persistence. In this respect, the relative degree of market competition seems to be an important parameter in explaining the size and volatility of relative price responses to symmetric shocks across euro area countries.

## 7. Conclusion

This paper draws conclusions based on a construction of a theoretical two-country two-sector DSGE model with both economies operating in a common monetary union. We are able to produce and show the existence of a HBS effect in a calibrated structural dynamic setting of a DSGE model by introducing a quality improvement mechanism that helps to explain why prices grow when productivity increases, especially in catching-up economies, as were the new EU member states in the 2000. In the estimated model based on the Slovene data we are able to show the increase of prices in both sectors, however we cannot confirm the HBS effect completely, since the tradable sector prices increase slightly more than the non-tradable sector prices when we induce a tradable sector productivity shock into the estimated model. Quality improvement mechanism affects marginal costs by requiring the use of more advanced inputs in the production process. The quality improvement of goods overcomes the typical open economy theoretical specification that reduces the relative prices of domestic tradable goods relative to the foreign prices, and consequently worsens the terms of trade for the domestic economy. Despite showing the presence of the HBS effect, the effect *per se* is not large enough to pose significant risks to central banks in their quest for price stability.

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## Appendices

### Appendix A: Prior and posterior distribution

Figure A1. Prior (dashed line) and posterior distribution (solid line) of the estimated shocks

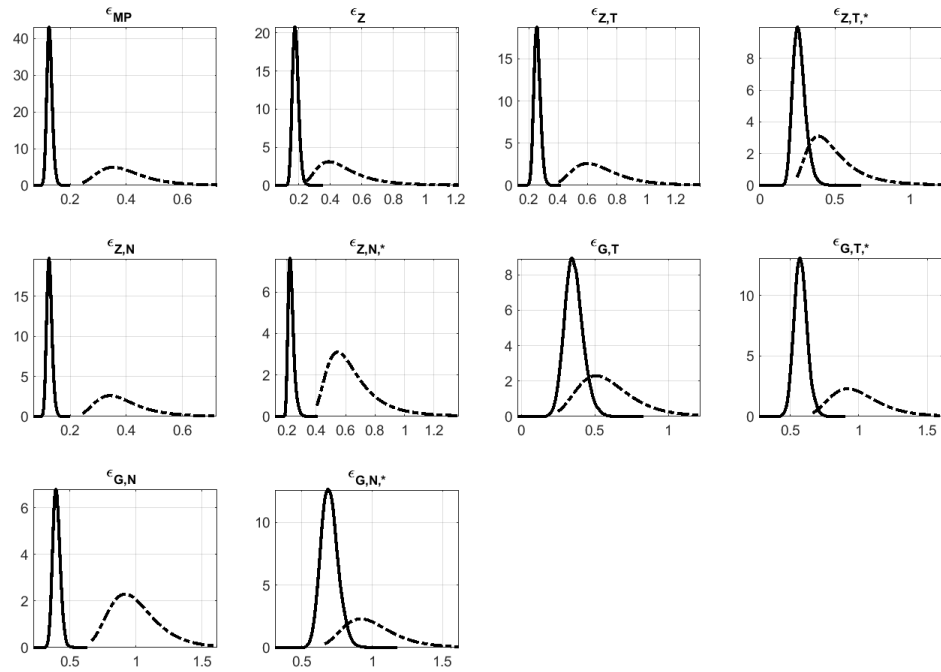
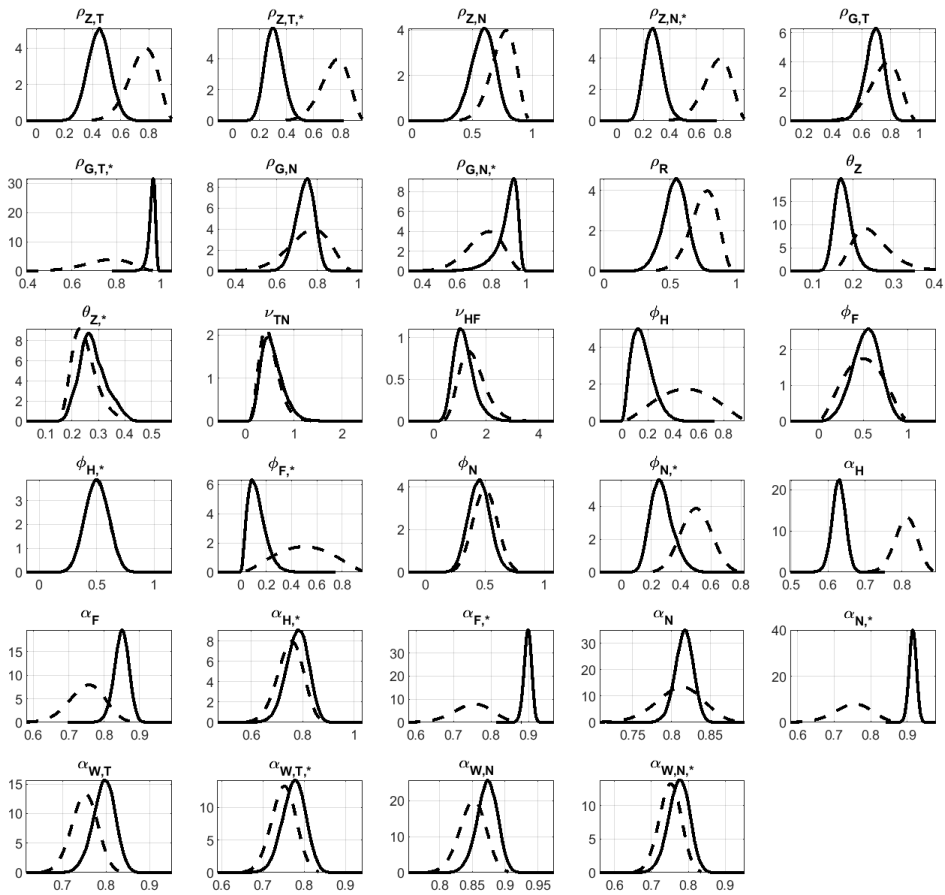




Figure A2. Prior (dashed line) and posterior distribution (solid line) of the estimated parameters



## Appendix B: Exogenous shocks

Figure B1. Exogenous shocks

