Macroeconomic Dynamics in Macedonia and Slovakia: Structural Estimation and Comparison

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Abstract

This paper estimates the structural model of Linde *et al.* (2008) using data for Macedonia and Slovakia. A comparison of the estimated model parameters suggest that, in Slovakia, the output gap is less sensitive to real interest rate movements and prices experience greater inertia. The estimated monetary policy reaction functions present Macedonia and Slovakia as inflation targeters, with Macedonia as the more conservative one, despite its officially applied exchange rate targeting regime. The differences in estimated parameters imply differing transmission mechanisms for Macedonia and Slovakia. Consequently, the variance of domestic variables in Slovakia is most influenced by monetary policy shocks, while there is no single dominating shock explaining the volatility of Macedonia's macroeconomic variables. The exchange rate shock, the monetary policy shock and the demand shock are jointly important in determining the volatility of Macedonia's variables. The model simulations indicate that Macedonia experiences lower output gap and inflation volatility than Slovakia. This comes, nevertheless, at the cost of higher interest rate and real exchange rate volatility in Macedonia, which could be an indication of more volatile financial markets.

Keywords: Structural Open-Economy Model, Bayesian Estimation, Eastern European Transition Economies.

JEL Classification: E32, E50, F41

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1. Introduction

The relation between macroeconomic stability and economic growth has been studied and emphasized for some time in both academic and policy circles, most recently by Hnatkovska and Loayza (2004) and Iradian (2007), among others. There also appears to be an important link between better structural, pro-growth policies and enhanced macroeconomic stabilization. This link is equally important, since macroeconomic stabilization is conducted under the structural constraints that characterize each national economy. Understanding the structural constraints to economic stabilization is therefore important for monetary policy to be implemented effectively, especially with regards to an appropriate choice of monetary policy regimes.

This paper estimates and compares structural characteristics of Macedonia and Slovakia. Macedonia and Slovakia are small, landlocked Eastern European countries that emerged from the shadow of central planning in 1993. Macedonia lags behind Slovakia in terms of income convergence to developed countries and the transition to a modern market economy. Nevertheless, Slovakia, as a potential role model for Macedonia in terms of economic development (see World Bank, 2009), provides an interesting counterfactual to the de-facto applied monetary policy regime (following the IMF classification). While Macedonia has been a de-facto exchange rate targeter for the period studied in this paper, Slovakia has been an inflation targeter, most recently in the context of the Exchange Rate Mechanism II (ERMII). Comparing the structural estimates for the two economies could thus help determine whether the de-facto monetary policy regime is effective or whether it is potentially creating problems for economic stabilization and economic growth in Macedonia. This paper is one of the first in the literature to estimate a fully microfounded open economy model with a wide range of rigidities for Macedonia and Slovakia, which could potentially be used as an analytical tool by policy makers in the two countries.

The estimated structural, open-economy models for Macedonia and Slovakia suggest the following findings. Slovakia has a significantly higher elasticity of intertemporal substitution as well as export share in domestic production than Macedonia, and a significantly lower share of imports in consumption and the elasticity of substitution across the domestically produced and imported goods. These results suggest that a weaker credit channel of monetary policy exists in Slovakia. The estimated model also suggests that Slovakia has been experiencing significantly higher price rigidity than Macedonia due to differences concerning the production technology and a relatively lower share of firms that optimally reset their prices. The estimated monetary policy reaction functions to inflation, the output gap, the euro area interest rate and the exchange rate show that Macedonia and Slovakia are inflation targeters. This is an expected result for Slovakia, which officially applies an inflation targeting regime, but contradicts the official pegged exchange rate regime applied by Macedonia. The results of this study show further that Macedonia has a lower output gap and inflation volatility than Slovakia, which comes at the cost of higher volatility in the interest rate and real exchange rate, and thus possibly higher volatility in financial markets.

The remainder of the paper is organized as follows. Section two discusses the model estimated for Macedonia and Slovakia. Section three describes the data and estimation method. Section four discusses the estimation results and the differences between Macedonia and Slovakia. Section five presents the impulse response analysis. Section six looks into the variance decomposition of the simulated variables from the estimated model. Section seven summarizes and concludes.

2. The Estimated Model

The open economy model that is estimated is the aggregate demand-aggregate supply (AD-AS) model of Linde *et al.* (2008). This model allows for gradual exchange rate pass-through (following Adolfson, 2001; and Monacelli, 2003) and imperfect financial integration (as in Benigno 2001, among others). Further, the model allows for sticky prices by making firms face quadratic adjustment costs in pricing (following Rotemberg, 1982) and inertia in domestic and imported inflation by assuming that a fraction of firms follow a backward-looking rule of thumb when resetting their prices. Moreover, the model introduces inertia in output originating from habit formation in consumer preferences (following e.g. Smets and Wouters, 2003). The main equations of the model in log-linearized form are presented and discussed below, and the model's derivation and microfoundations can be found in Linde *et al.* (2008, Appendix A).

$$\begin{aligned} y_t = \left(1-a_y\right) y_{t-1} + a_y \mathrm{E}_t y_{t+1} + a_r \left[i_t - \mathrm{E}_t \pi_{t+1}^d \right] + a_{\tau 1} \tau_{t-1} + a_{\tau 2} \tau_t + a_{\tau 3} \mathrm{E}_t \tau_{t+1} \\ + a_{\tau f 1} \tau_{t-1}^f + a_{\tau f 2} \tau_t^f + a_{\tau f 3} \mathrm{E}_t \tau_{t+1}^f + a_{yf1} y_{t-1}^f + a_{yf2} y_t^f + a_{yf3} \mathrm{E}_t y_{t+1}^f + u_t^y \end{aligned} \tag{1}$$

$$i_t - i_t^f = \mathrm{E}_t \Delta s_{t+1} - \phi a_t \tag{2}$$

$$a_t = d_a a_{t-1} + d_y y_t + d_\tau \tau_t + d_{\tau f} \tau_t^f + d_{yf} y_t^f + d_x x_t + \varepsilon_x \tag{3}$$

$$x_t = e_y y_t + e_\tau \tau_t + e_{\tau f} \tau_t^f + e_{yf} y_t^f \tag{4}$$

$$q_t \equiv s_t + p_t^f - p_t^c = -\tau_t^f - \omega_m \tau_t \tag{5}$$

$$\pi_t^c = \omega_m \pi_t^m + (1 - \omega_m)\pi_t^d = \pi_t^d + \omega_m \Delta\tau_t \tag{6}$$

$$\pi_t^d = b_{\pi 1} \mathrm{E}_t \pi_{t+1}^d + b_{\pi 2} \pi_{t-1}^d + b_{\pi 3} \pi_{t-2}^d + b_y y_t + b_\tau \tau_t + u_t^d \tag{7}$$

$$\pi_t^m = c_{\pi 1} \mathrm{E}_t \pi_{t+1}^m + c_{\pi 2} \pi_{t-1}^m + c_{\pi 3} \pi_{t-2}^m + c_\tau \left[\tau_t + \tau_t^f\right] \tag{8}$$

Equation (1) is an aggregate demand equation in log-linearized form. In its derivation, it is postulated that households attain their utility from consuming bundles of domestic and imported goods and are assumed to value consumption relative to past aggregate consumption. Namely, household preferences are assumed to show external habit formation of the 'Catching up with the Joneses' type (see Abel, 1990; Smets and Wouters, 2003). The optimization problem of households is outlined in Appendix A. In Equation (1), the current output gap thus responds positively to one-period lagged output gap and expected future output gap, and is expected to respond negatively to increases in the real interest rate. Further, it responds to past, current and future domestic terms of trade and foreign terms of trade. In the model of Linde *et al.* (2008), the imperfect exchange rate pass-through means that import prices do not necessarily coincide with world market prices converted into domestic currency units, so the law of one price (LOOP) is not enforced to hold. Allowing for the possibility of an LOOP wedge means that one can identify two different types of terms of trade in the model. The first is the domestic terms of trade, i.e. the relative price between domestic and imported goods as perceived by the domestic resident, $\tau_t \equiv p_t^m - p_t^d$. The second is the foreign terms of trade, i.e. the relative price between the domestically produced good and the imported good on the world market, $\tau_t^f \equiv p_t^d - s_t - p_t^f$, where s_t stands for exchange rate. With complete exchange rate pass-through, $p_t^m = p_t^f + s_t$. However, under imperfect pass-through when $p_t^m \neq p_t^f + s_t$, there is a deviation from the law of one price given as $\delta_t = \tau_t^f + \tau_t$. Additionally, the current output gap responds to fluctuations in foreign demand and is affected by a household preference shock (see Appendix A for a detailed definition of the shock). Finally, the *a*'s with subscripts are composite coefficients. Their definition in terms of the deep structural coefficients, which we estimate from historical data, is shown in Appendix B.

Equation (2) is the uncovered interest parity equation that postulates that an expected change in the exchange rate equals the interest rate differential plus the currency risk premium. This equation results from the solution of households' optimal allocation of bond holdings described in Appendix A. In periods when the economy is a net borrower, the domestic interest rate is higher than the foreign interest rate. Correspondingly, when there is no expected exchange rate depreciation, and when the economy is a net lender, the domestic interest rate is lower than the foreign interest rate. Movements in the net foreign asset position thus affect the interest rate differential between the domestic and foreign economies.

The risk premium described in Equation (3) is a function of its past value, the domestic and foreign output gaps, domestic and foreign terms of trade and real profits. In addition, we allow for a Normally distributed, autocorrelated shock to the currency risk premium. The definition of the composite parameters, *d*'s, in terms of the structural parameters is provided in Appendix B.

Equation (4) describes the dynamics of real profits, where real profits depend on the domestic output gap, domestic terms of trade, foreign terms of trade and the foreign output gap. The definition of the composite parameters, *e*'s, in terms of the structural parameters is also provided in Appendix B.

Equation (5) is the definition of the real exchange rate as the nominal exchange rate times the ratio of price levels in the foreign and domestic economy. The real exchange rate can be expressed as the negative of the sum of the foreign terms of trade and weighted domestic terms of trade using the import share for the domestic economy.

Equation (6) describes CPI inflation as the weighted average of import inflation and domestic inflation rates where the respective weight is the import share in GDP for the domestic economy.

Equation (7) and (8) describe the domestic and import inflation dynamics -- the main components of aggregate supply dynamics. Following Smets and Wouters (2003), the model of Linde *et al.* (2008) that we estimate in this paper, has two sets of firms. One, a monopolistically competitive imported-goods sector with sticky prices, in which firms purchase a foreign good at given world prices (its marginal cost), and turn it into a differentiated import good that can be used for either domestic consumption or as an input in production. Two, firms in the domestic sector which produce differentiated goods using both domestic and imported inputs. Both categories of firms face a quadratic cost of price adjustment, following Rotemberg (1982). Further, it is assumed that only a subset of firms reoptimize their price each period, whereas the remaining firms follow a simple rule of thumb when resetting their prices, that is, as in Gali and Gertler (1999) firms index to past inflation. The optimization problems of firms in the imported-goods sector and the domestic sector are described in Appendix A. As described in Equation (7), domestic inflation depends on expected domestic inflation one-period ahead, one- and two-periods lagged domestic inflation, the domestic output gap, domestic terms of trade and the domestic cost-push shock. According to Equation (8), import inflation depends on expected import inflation one-period ahead, one- and two-periods lagged import inflation and the sum of the domestic and foreign terms of trade. As in Linde *et al.* (2008), we do not consider an external cost-push shock.

2.1. Policy Reaction Function

While the IMF classifies the monetary policy regime of Macedonia as a fixed exchange rate one (with respect to the EUR)[1], the monetary policy regime applied by the Slovak National Bank (SNB) has been classified as inflation targeting since December 2004[2], and recently applied within the context of ERMII which the Slovak Republic joined in 2007. Although one may argue for specific reaction functions in each country, we opt for a unified reaction function that encompasses both exchange rate and inflation targeting features. Benigno *et al.* (2007) propose a general reaction function for exchange rate targeters where the policy rate is adjusted with respect to the movements of the anchor currency's policy rate and the change in the exchange rate, while allowing for some monetary policy discretion:

$$i_t = i_t^* + \beta \Delta s_t + \varepsilon_{MP,t} \tag{9}$$

Inflation targeting is traditionally represented by the Taylor rule. The Taylor rule has been found empirically plausible and reasonably robust to different model structures (see Svensson, 2000). In some circumstances, the Taylor rule can also be used to describe optimizing behavior (see Benigno and Benigno, 2003):

$$i_t = \rho_i i_{t-1} + (1-\rho_i)(\alpha \pi_t + \beta y_t) + \xi_{MP,t} \tag{10}$$

The specification in equation (10) implies that the monetary authority responds to inflation and the output gap, while at the same time adhering to a certain degree of inertia in i_t. The last term represents discretionary adjustments in the interest rate in the context of the described policy rule.

[1] This regime has been applied by Macedonia since 1995 with a single devaluation in 1997.

[2] Nevertheless, implicit inflation targeting was applied by the SNB since 1998 when the pegged exchange rate framework was abandoned and a combination of managed floating and implicit inflation targeting was adopted.

Given our aim to employ a policy rule that would encompass both exchange rate and inflation targeting features we assume the following central bank reaction function:

$$i_t = \rho_i i_{t-1} + (1-\rho_i)\left(\alpha_\pi \pi_t + \alpha_y y_t + \alpha_s \Delta s_t + \alpha_i i_t^*\right) + \varepsilon_{MP,t} \quad (11)$$

While the de jure IMF classification suggests the use of differentiated policy rules, the policy rule in Equation (11) allows for testing which of the two rules might reflect better the historically applied, de-facto monetary policy regime based on the significance of the respective coefficient estimates in Equation (11) using historical data.

The foreign (euro area) block is described by a VAR including the main foreign macroeconomic variables, i.e. the foreign output gap, y_t^F, foreign inflation, π_t^F, and foreign interest rate, i_t^F:

$$X_t = \mathrm{B} X_{t-1} + \varepsilon_{X,t} \quad (12)$$

where $X_t \equiv \left[y_t^F, \pi_t^F, i_t^F \right]'$, B is a matrix of coefficients, and the elements of the vector of shocks, $\varepsilon_{X,t}$, are assumed to be Normally distributed and are allowed to be autocorrelated. This implies that, by substitution for the autocorrelated shocks, the estimated model for the foreign block will take the form of VAR(2).

3. Data and the Estimation Method

In order to maximize the available data coverage while considering the data quality, we use quarterly data for Macedonia from 1997Q1 to 2009Q1, and for the Slovak Republic from 1995Q1 to 20079Q1. All data for the Slovak Republic were obtained from the IMF's International Financial Statistic except the nominal interest rate which was obtained from Datastream. For both countries, the output gap was constructed as a deviation of quarterly real GDP in logs from its potential levels estimated using the Hodrick-Prescott filter. The GDP series for Macedonia was obtained from the National Statistical Office. Inflation was calculated as an annualized percentage change in quarterly CPI, which for Macedonia was obtained from the National Statistical Office. The interest rate used for the Slovak Republic is the three-month interbank rate (middle rate) from Datastream. This rate does well in tracking the current monetary policy rate (the repo rate), on which data are available only since 2000. The interest rate used for Macedonia is the Central Bank Bill rate obtained from the National Bank of Macedonia. We have not used the interbank rate for Macedonia as the interbank money market was quite inactive over the analyzed period. The observable exchange rate employed is the real effective exchange rate for Macedonia that was obtained from the National Bank of Macedonia.

All data are demeaned and detrended prior to the estimation using a linear trend, except for the output gap. Giordani (2004) has recently pointed out that working with demeaned data avoids dealing with parameter instability and structural breaks which, he finds, largely affect the unconditional mean of the modeled series.

There have been several estimation methods used in the literature to fit New Keynesian models (NKM) to empirical data. One method that is often employed is the Generalized Method of Moments (GMM) (see, e.g., Gali and Gertler, 1999, and others). However, Linde (2005) showed recently that GMM estimates of the parameters of a simple New Keynesian model are likely to be estimated imprecisely and with a bias. It has thus become common practice to estimate New Keynesian models using a full information Maximum Likelihood (ML) approach. One of the drawbacks of using ML is that parameters can take on corner solutions or theoretically implausible values. Additionally, it is often the case that the log-likelihood function is flat in certain directions of the parameter space or extremely hilly overall, so that without careful constraints on the parameters space it is difficult to numerically maximize the log-likelihood function (see An and Schorfheide, 2005, for more details). Rather than imposing constraints on the parameter space in ML estimation, it is more natural to add a probabilistic statement, or a prior belief, on the parameter space of the estimated model. This can be done easily within a Bayesian estimation approach which combines theoretical constraints and prior beliefs on the parameter space with the information contained in the data (see, e.g., Adolfson *et al.*, 2008). Due to these reasons, we use the Bayesian estimation method to obtain estimates of and draw inference on the model parameters.

The Bayesian approach to estimating a NKM with nominal rigidities consists of the following steps. Firstly, the log-linearized rational expectation model in (1)-(8), (11) and (12) is rewritten into the state-space form and solved using the QZ solution algorithm of Sims (2002). In our case, the solved model has a VAR(3) structure which readily allows to compute the likelihood function. Combining the likelihood function of the solved model with the prior densities on the parameters then defines the posterior density. That is, given the priors $p(\theta)$, where θ is a vector containing the model parameters, the posterior density $p(\theta|\boldsymbol{Y})$ is proportional to the product of the likelihood function of the solved model and the priors:

$$p(\theta|\boldsymbol{Y}) \propto L(\theta|\boldsymbol{Y})p(\theta) \quad (13)$$

where $L(\theta|\boldsymbol{Y})$ is the likelihood function conditional on data $\boldsymbol{Y}$. Note that the priors that we use are mutually independent, so that $p(\theta)$ is constructed as the product of the individual priors on the structural parameters given in the second column of Table 1 for Slovakia and Macedonia. The posterior in (13) is generally a non-linear function of the structural parameters θ and is maximized using a numerical optimization algorithm.[3] The values of the parameters at the posterior mode, together with the corresponding Hessian matrix are then used to start the random walk Metropolis-Hastings sampling algorithm to obtain draws from the entire posterior distribution. Proposals in the sampling algorithm are drawn from a multivariate Normal distribution, where a scaling factor of 0.1 was used, resulting in an acceptance rate of 30% and 26% for Macedonia and Slovakia, respectively. See An and Schorfheide (2005) for details on the Metropolis-Hastings sampling algorithm and the role of the scaling factor in the sampler. We ran two chains of 200,000 draws, where the first 50% of each chain were discarded as a burn-in sample.[4]

4. Discussion of Estimation Results

Table 1 presents Bayesian estimates of the structural parameters of the model. The parameters' names are shown in column one, the priors for the corresponding parameters in column two, posterior mean estimates for Macedonia and Slovakia in columns three and six and the 95 % Bayesian confidence intervals in columns four to five for Macedonia and in columns seven to eight for Slovakia. We have centered the priors on the parameter estimates of Linde *et al.* (2008). In some instances, the theoretical priors suggest restricting the support of the parameter space so that the use of Beta or Inverse Gamma distributions would be theoretically justified. Nevertheless, for computational reasons, we have chosen in most instances to use Normal priors and to restrict the support by using appropriate values of the scale parameter, i.e., the magnitude of the standard deviation parameter. This approach has proven to ensure better behavior of the optimizer to estimate the posterior modes and the Hessian matrix of the structural parameters. Also, when estimating the VAR structure of the foreign block (represented by the euro area) we have used unconstrained ML estimation to

[3] We have used a simulated annealing algorithm for this. Note that, as with ML estimation, it is the log of the posterior density that is maximized.

[4] We verify that the sampling algorithm converged successfully by monitoring standard multivariate convergence criteria due to Brooks and Gelman (1998), that is, we monitored the determinants of within sequence and between-sequence covariance matrices of the iterates.

ensure that the VAR describes the data as closely as possible. In the Bayesian estimations for Macedonia and Slovakia, we have fixed the VAR parameters for the euro area at the ML estimates to signify the exogeneity of the euro area block in the model. The ML parameter estimates for the VAR describing the euro area are reported in Appendix C.

Table 1: Bayesian Estimates of the Structural Parameters

		Macedonia				**Slovakia**		
Parameter	**Prior**	**Posterior Mean**	**95% Bayesian Confind. Interval**			**Posterior Mean**	**95% Bayesian Confind. Interval**	
h	Normal(0.8,0.3)	0.7175	0.5742	0.8541		0.6806	0.6068	0.8651
sigma	Normal(1.1,5.0)	**2.3249**	1.9166	2.7837		**4.9617**	3.1271	7.8800
omega_x	Normal(0.5,0.3)	**0.3599**	0.3468	0.3700		**0.5645**	0.5452	0.6047
omega_m	Normal(0.3,0.3)	**0.3330**	0.3239	0.3424		**0.2568**	0.2232	0.2842
nu	Normal(0.9,5.0)	**0.8461**	0.7360	0.9616		**0.4846**	0.4292	0.5727
chi_f	Normal(0.5,0.3)	0.5643	0.0524	0.9435		0.1832	-0.0989	0.4110
nu_d	Normal(15.3,5.0)	15.8887	6.9929	24.0983		18.6005	9.2261	27.581
nu_m	Normal(6.0,2.0)	5.2473	2.5685	7.6564		5.8217	3.4340	8.5010
theta	Normal(0.8,0.3)	**0.9870**	0.9810	0.9945		**0.1955**	0.1211	0.2973
kappa	Normal(0.8,0.3)	0.9386	0.6411	1.2114		0.7529	0.5105	1.0525
gamma_d	Normal(13.0,5.0)	12.9221	6.7470	18.0505		8.1649	2.0066	13.7014
gamma_m	Normal(18.9,5.0)	22.7110	11.8201	29.2478		14.9258	12.3283	17.603
alpha_d	Normal(0.5,0.3)	0.4533	0.3336	0.6229		0.5628	0.5137	0.6233
alpha_m	Normal(0.6,0.3)	**0.5477**	0.2161	0.7922		**0.8519**	0.7772	0.9148
phi	Normal(0.001,0.0)	0.0007	-0.0009	0.0019		0.0013	-0.0000	0.0028
rho_uy	Beta(0.1,0.2)	0.0003	0.0000	0.0007		0.0009	0.0000	0.0031
rho_x	Beta(0.7,0.2)	**0.8666**	0.8203	0.9251		**0.4621**	0.3336	0.5556
rho_ud	Beta(0.1,0.2)	0.0021	0.0000	0.0052		0.0004	0.0000	0.0008
rho_i	Beta(0.6,0.2)	**0.7018**	0.6376	0.7528		**0.8038**	0.7889	0.8174
beta_pi	Normal(2.0,1.0)	**2.2859**	1.9846	2.6553		**1.3903**	0.7183	1.8011
beta_y	Normal(0.7,1.0)	**0.1582**	-0.2767	0.7369		**1.5399**	1.2384	1.8290
beta_if	Normal(0.1,1.0)	-0.2615	-0.5466	-0.0422		0.0379	-0.0420	0.1192
beta_ds	Normal(0.0,1.0)	0.1083	-0.0133	0.2358		-0.1530	-0.2136	-0.109
std(e_y)	InvGamma(1.3,5.0)	1.2451	1.0706	1.4417		1.1755	0.9238	1.4206
std(e_x)	InvGamma(4.4,5.0)	2.8599	1.5455	4.5775		4.3563	3.4609	5.5465
std(e_d)	InvGamma(1.1,5.0)	**2.3387**	2.1127	2.8908		**1.4188**	1.1528	1.6797
std(e_mp)	InvGamma(3.1,5.0)	3.4022	2.5345	4.2223		3.3203	2.9691	3.9747
Log data density [Laplace approximation]		**-542.856162 -533.612189**				**-671.568681 -619.2612**		

Note: Beta(*a*, *b*), Normal(*a*, *b*) and InvGamma(*a*, *b*) are the Beta, Normal and Inverse Gamma densities respectively, with *a* and *b* being location and scale parameters. rho_(.)and std(e_(.)) are respectively the autocorrelation and standard deviation of the structural shocks. std() stands for the standard deviation of a variable. The bolded figures indicate significant differences in parameter estimates across Macedonia and Slovakia.

The habit formation in consumption (*h*) appears to be somewhat stronger in Macedonia (*h*=0.72) compared to Slovakia (*h*=0.68), possibly giving rise to a higher output rigidity in Macedonia. While the two estimates are not statistically different, given that the 95% confidence intervals for the two estimates overlap, they are both significantly different from zero and well identified by the data given that the marginal posterior distributions in both cases dominate the prior distributions. The estimates of the elasticity of intertemporal substitution (*sigma*) imply that the elasticity is significantly higher in Slovakia (*sigma*=4.96) than in Macedonia (*sigma*=2.32). The export share in domestic production (*omega_x*) is estimated to be significantly higher in Slovakia (*omega_x*=0.56) than in Macedonia (*omega_x*=0.36). Together, higher *sigma* and *omega_x* and similar *h* imply lower sensitivity of output to movements in the *ex-ante* real interest rates in Slovakia (see the definition of the *a_r* coefficient in Appendix B). Furthermore, the share of imports in consumption (*omega_m*) and the elasticity of substitution across the domestically produced and imported goods (*nu*) are both estimated to be significantly higher in Macedonia (*omega_m*=0.85; *nu*=0.33) than in Slovakia (*omega_m*=0.46; *nu*=0.26). The elasticity of foreign consumption (chi_f) is estimated to be smaller for Slovakia, however, only the Macedonian estimate is well identified by the data, as the posterior distributions dominate the respective priors. This suggests relatively higher sensitivity of the output gap in Macedonia to foreign demand.

The estimates of the elasticities of substitution across domestically produced and imported goods (*nu_d* and *nu_m*) are not significantly different for Macedonia (*nu_d*=15.9 and *nu_m*=5.2) and Slovakia (*nu_d*=18.6 and *nu_m*=5.8) and in both countries the elasticity of substitution across domestically produced goods is significantly higher than the elasticity of substitution across imported goods. The estimate of the production technology parameter (*theta*) for Macedonia (*theta*=0.987) is significantly higher than the *theta* estimated for Slovakia (0.196). While the share of imports in intermediate goods (*kappa*) appears to be higher in Macedonia (*kappa*=0.939) than in Slovakia (*kappa*=0.753), the estimates are not statistically different because they are not well identified by the data. While the price adjustment costs in the domestically produced goods' sector (*gamma_d*) and imported goods' sector (*gamma_m*) appear to be higher in Macedonia (12.9 and 22.7, respectively) than in Slovakia (8.2 and 14.2, respectively) the associated confidence intervals for the corresponding estimates are wide so that the differences in estimates between Macedonia and Slovakia are found insignificant. The estimated fraction of firms producing domestic goods (*alpha_d*) that does not optimize their price is not statistically different in Macedonia (*alpha_d*=0.45) and Slovakia (*alpha_d*=0.56). For both countries the estimated fraction of firms that do not optimize their price in the sector for domestically produced goods is smaller than the analogous fraction estimated for the sector of imported goods (*alpha_m*). Only in Slovakia though, *alpha_d* and *alpha_m* are statistically different. Further, for Macedonia *alpha_d* is estimated at 0.548 and for Slovakia is estimated at 0.852, and the difference is statistically significant, i.e. there is a larger fraction of firms in the import sector in Slovakia that do not re-optimize their price. Given that the estimates of *gamma_d*'s, *gamma_m*'s and *alpha_d*'s are not statistically different for Macedonia and Slovakia, and given that *alpha_m*'s are estimated to be significantly higher in Slovakia, the price rigidity in Slovakia is thus estimated to be significantly higher, at least in the import goods sector – see the definition of *b_pi1*, *b_pi2* and *b_pi3* in Appendix B.

The estimated sensitivity of the currency risk premium to changes in net foreign assets (*phi*) appears to be higher for Slovakia (*phi*=0.0013) than for Macedonia (*phi*=0.0007). However, the two estimates are not statistically different. The autocorrelation of the domestic demand (consumer preference) shock (*rho_uy*) is estimated to be very small and positive for both Macedonia and Slovakia. On the other hand, the autocorrelation of the exchange rate shock (*rho_x*) is estimated to be significantly higher for Macedonia (*rho_x*=0.87) than for Slovakia (*rho_x*=0.46). Autocorrelation of the domestic supply shocks in both Macedonia and Slovakia and estimated to be close to zero.

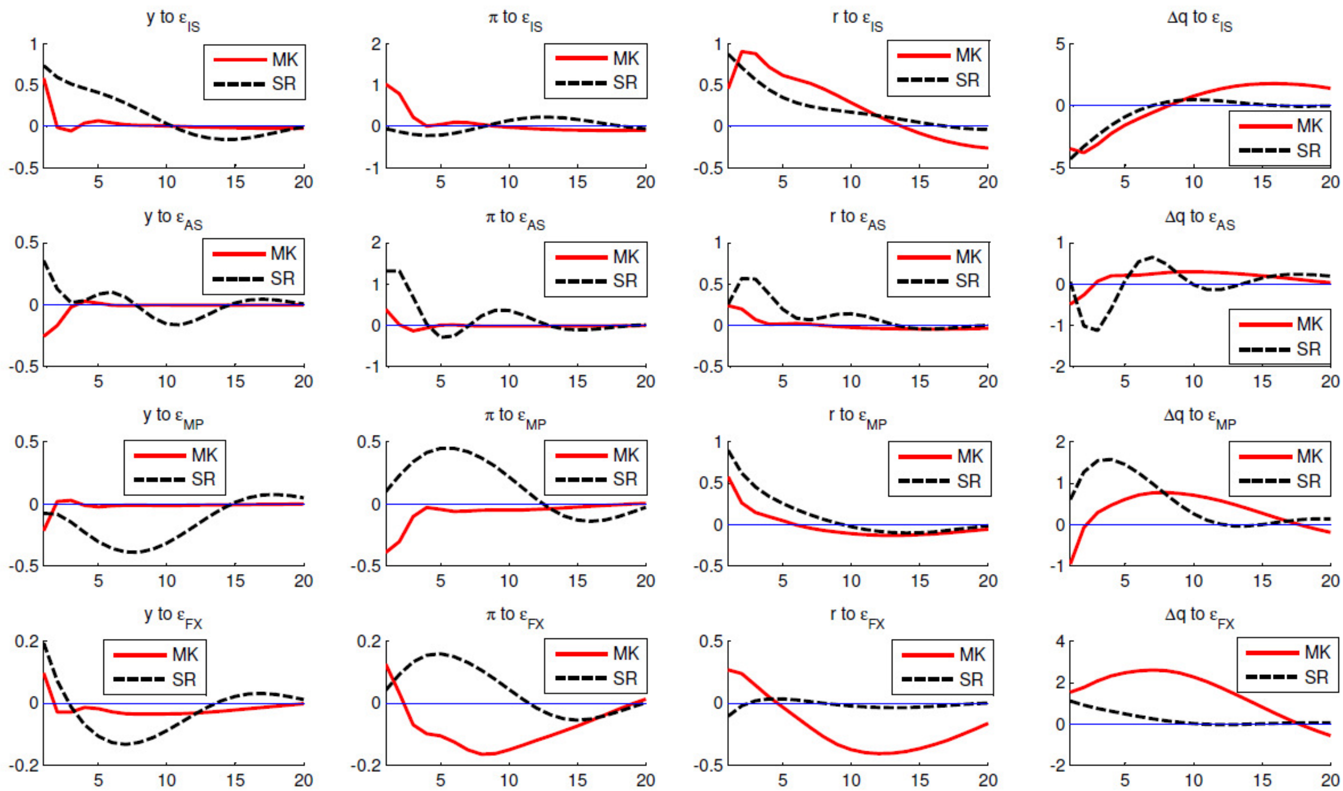
Concerning the estimated coefficient of the monetary policy (MP) response function, the degree of interest rate smoothing (*rho_i*) is found to be significantly higher in Slovakia, at 0.8, than in Macedonia, at 0.7. The response of MP to inflation (*beta_pi*) is estimated to be significantly stronger in Macedonia, of 2.29, than in Slovakia, 1.39. On the other hand, the response of MP to the output gap (*beta_y*) is estimated to be significantly higher in Slovakia (1.54) than in Macedonia (0.16). Following Svensson (2000), Macedonia's central bank (the NBRM) could be classified as a relatively more conservative central bank. The response of MP to changes in the euro area interest rate (*beta_if*) is significantly negative in Macedonia (-0.26) while it is estimated to be insignificant in Slovakia. In contrast, the MP response to changes in the exchange rate is estimated to be significantly negative in Slovakia (-0.15) and not different from zero in Macedonia. The latter two negative estimates for Macedonia and Slovakia, respectively, are in contradiction with explicit exchange rate targeting, and could have, in this context, a destabilizing effect on the economy. Although this could be expected for Slovakia, where the official monetary policy regime is inflation targeting, the result contradicts the official monetary policy regime of a pegged exchange rate within bands for Macedonia, which appears to behave as a conservative inflation targeter.

The estimated sizes of the structural shocks for Macedonia and Slovakia suggest the following. The smallest standard deviation and thus average size of the shock is estimated for the domestic demand (preference) shock (*e_y*) of 1.25 for Macedonia and 1.18 for Slovakia. The largest estimates of a shock's size, on the other hand, are the exchange rate shocks (*e_x*) for Slovakia and the monetary policy shock (*e_mp*) for Macedonia with respective estimated standard deviations of 4.36 and 3.40. The only statistically different estimates of the size of the corresponding structural shocks for Macedonia and Slovakia pertain to the domestic supply shocks (*e_d*), where the average size of this shock is found to be significantly lower in Slovakia (1.42, versus 2.34 for Macedonia).

5. Impulse Response Analysis

This section compares the transmission mechanisms in Macedonia and Slovakia by looking into the dynamics of corresponding impulse response functions (IRFs). We use the IRFs with respect to one unit shock to abstract from the influence of different sizes of shocks on the IRFs and thus ensure comparability of the IRFs across the two countries. Figure 1 shows the IRFs to unit structural shocks for Macedonia and Slovakia. Namely, the columns of Figure 1 show the IRFs of the output gap, inflation, interest rate and the change in the real exchange rate to: (i) the domestic demand (preference) shock, *eta_IS*, in the first row, (ii) the domestic supply shock, *eta_AS*, in the second row, (iii) the monetary policy shock, *eta_MP*, in the third row, and (iv) the exchange rate shock, *eta_FX*, in the fourth row.

Figure 1: Impulse Response Functions of Domestic Variables to Unit Structural Shocks



Consider the first row of Figure 1. When the unit domestic demand (preference) shock hits the Macedonian and Slovakian economies, the output gap increases at impact less than by a unit in both countries -- and relatively more in Slovakia. The opening output gap causes marginal costs to rise and increase the CPI inflation in Macedonia but not in Slovakia. Nevertheless, with the opening, positive output gap in both economies and rising inflation in Macedonia, monetary authorities in both countries raise the interest rate at the impact of the demand shock. While for Slovakia the peak response of the interest rate appears at impact, for Macedonia this peak occurs with a lag of one quarter. The hike in the monetary policy rate causes real exchange rate appreciation in both countries where in Macedonia this appreciation is further reinforced by faster growing prices. The tightening MP stance and appreciating real exchange rate cool down the economies of both countries after the positive demand shock so that they gradually return to their steady states. While the responses of the interest rate and exchange rate to the shock appear to be fairly similar in the two countries, the responses of the output gap and inflation differ noticeably.[5] Namely, the response of the output gap in Macedonia is similar to that in Slovakia at impact but adjusts back to the steady state much faster, in about two quarters as opposed to in about ten quarters in Slovakia. The impact of the demand shock on CPI inflation in Macedonia is significantly positive at impact and lasting for about four quarters, whereas in Slovakia this impact is not statistically significant.

Consider the second row of Figure 1. When the unit supply (AS) shock hits the economy, inflation in Macedonia rises at impact by less than a unit while inflation in Slovakia rises by more than a unit. In both countries the monetary authorities react by increasing interest rates where the interest rate response in Macedonia reaches its peak at impact while that in Slovakia reaches its peak with one-period lag. The exchange rate appreciates at impact in Macedonia due to the dominating effect of the increased interest rate, whereas in Slovakia the exchange rate appreciates only with one-period lag. In Macedonia, because the interest rate rises more than inflation and the exchange rate appreciates, monetary conditions tighten and the output gap drops to the negative territory. On the other hand, in Slovakia, because the interest rate rises less than inflation, even at its peak, and the exchange rate appreciation comes only with a lag, the monetary conditions loosen and the output gap opens to the positive territory. Hence, the IRFs to the supply shock are not only more pronounced and longer lasting for Slovakia, but the output gap responds in the opposite direction in Slovakia than in Macedonia.

[5] We do not report the estimated confidence intervals in Figure 1 for the sake of better readability.

Consider the third row of Figure 1. Once the (discretionary) unit monetary policy shock hits the economy, the interest rate both in Macedonia and Slovakia increases by less than one unit, where in Macedonia the increase is smaller than in Slovakia. As a result, the output gap and inflation in Macedonia drop and the real exchange rate appreciates due to the increased real interest rate differential in favor of the Macedonian denar. Since the return of inflation and the output gap to their steady states requires easing of monetary conditions, the real exchange rate subsequently depreciates for several periods to facilitate this process. In Slovakia, the increase in the real interest rate sends the output gap slightly into the negative territory at impact. In contrary to Macedonia, the real exchange rate in Slovakia depreciates at impact and further on, as the expectation of exchange rate depreciation dominates the real exchange rate dynamics. Recall that the central bank of Slovakia puts much more weight on the output gap in its reaction function than does the central bank of Macedonia. The real exchange depreciation then passes through to higher inflation. Consequently, the worsening terms of trade, between the domestically produced goods and imports for Slovakia, keep the output gap in the negative territory for several periods. This is until the effects of the depreciating real exchange rate and declining real interest rate take over and bring the output gap back to the steady state. The inflation also returns gradually to the steady state as the high interest rate is sustained for several periods. In sum, the responses of the output gap and real exchange rate to an MP shock in Macedonia are dissimilar to the analogous responses in Slovakia. Also, the effect of the MP shock on the domestic variables, except for the real exchange rate, is relatively short-lived for Macedonia compared to Slovakia.

Finally, consider the IRFs in the third row of Figure 1. When the unit currency risk-premium shock hits the economy, the real exchange rate in Macedonia depreciates at impact and exhibits sustained depreciation for about 17 periods. In Slovakia, the real exchange rate also depreciates at impact but less so than in Macedonia and the depreciation is relatively short-lived. In Macedonia, the real exchange rate depreciation translates into a positive output gap and increasing inflation at impact. This prompts Macedonia's central bank to increase its policy rate, facilitating a gradual return of the real exchange rate back to the steady state. With the increased policy rate, the output gap returns back to the steady state in about two quarters while inflation dynamics shows a protracted swing into the negative territory before it returns back to the steady state. This overshoot of inflation into the negative territory could be explained by a significant second-order autocorrelation of inflation in Macedonia, for which the AR(1) coefficient is significantly positive while the AR(2) coefficient significantly negative. In Slovakia, the real exchange rate depreciation makes the output gap open in the positive direction, and inflation to hike up at impact and keep increasing for next five periods. The significant pass-through of the exchange rate into domestic inflation results in worsening domestic terms of trade in favor of imported goods. This makes the output gap overshoot in its adjustment into negative numbers, cooling down inflation, and with the continuing boost from depreciated exchange rate the output gap returns back to the steady state. The monetary policy reacts only mildly in the process due to the conflicting dynamics of inflation and the output gap. Recall that Slovakia's central bank places roughly equal weight on inflation and the output gap when adjusting its policy rate.

Overall, the transmission mechanisms are similar in Macedonia and Slovakia for some variables and shocks but distinct for others. The main differences could be observed in: (i) the response of the CPI inflation to domestic demand (preference) shock which is significantly positive for Macedonia and rather insignificant for Slovakia; (ii) the response of the output gap to the domestic supply shock which is significantly negative in Macedonia and significantly positive in Slovakia; (iii) the response of the real exchange rate to the monetary policy shock which is significantly negative at impact for Macedonia and significantly positive in Slovakia – the ensuing real exchange rate dynamics is then reflected in the inflation dynamics; (iv) the dynamics of the impulse response of inflation to the exchange rate shocks is U-shaped for Macedonia, while it exhibits a hump for Slovakia. These differences could be attributed mainly to the significantly different estimates of the structural parameters of the model including the coefficients of the policy response functions shown in Table 1 and discussed in Section 4.

6. Variance Decomposition

This section examines the effect of the differing transmission mechanisms in Macedonia and Slovakia on the relative volatility of the output gap, inflation, interest rate and real exchange rate – the variables of interest – and determines the main sources of this volatility, i.e. the most influential structural shocks, given the estimated transmission mechanism.

6.1. Unit Shocks

We simulate the variables of interest, using the estimated structural model for Macedonia and Slovakia, and compute their standard deviations and variance decomposition. The standard deviations of the structural shocks are initially set to one to isolate the effect of the differing transmission mechanisms from that of the differing sizes of structural shocks for Macedonia and Slovakia. Table 2 shows the computed standard deviations of the simulated variables of interest.

Table 2: Standard Deviations of Simulated Variables Based on Unit Shocks

Variable	Macedoani	Slovakia
y_d	0.8876	3.2131
pi_c	4.8551	3.3123
i	9.0532	3.3906
q	29.7350	11.7272

The results in Table 2 suggest that the macroeconomic transmission mechanism in Macedonia produces a lower standard deviation of the output gap than the mechanism in Slovakia, by about three times. On the other hand, the transmission mechanism in Macedonia appears to produce a higher standard deviation of inflation, interest rate and real exchange rate than does the transmission mechanism in Slovakia for similar variables, by about one and half times, three times and three times respectively. Therefore, while conditioning out the effect of the differing sizes of structural shocks, the estimated transmission mechanism for Macedonia appears to produce higher volatility of the domestic economy relative to Slovakia.

Table 3 shows the asymptotic variance decomposition for the variables of interest. The contributions of foreign shocks are calculated as a residual since they are reduced-form shocks and have not been structurally identified.

Table 3: Computed Variance Decompositions for Macedonia and Slovakia

	Macedonia					Slovakia				
Macedonia	**e_y**	**e_x**	**e_d**	**e_mp**	**e_F**	**e_y**	**e_x**	**e_d**	**e_mp**	**e_F**
y_d	45.26	3.13	11.97	6.37	33.27	18.5	1.35	2.61	9.57	67.97
pi_c	7.81	1.15	0.74	1.22	89.08	4.27	1.38	41.2	12.02	41.14
i	5.62	2.46	0.15	0.76	91.00	19.24	0.20	8.39	14.63	57.53
q	9.20	8.95	0.15	0.83	80.87	28.69	2.49	2.91	9.04	56.87

Note: This simulation uses shocks with unit standard deviation.

The results in Table 3 indicate that the variability of the output gap in Macedonia could be from about 45 percent attributed to the transmission of the demand (preference) shock, from about 12 percent to the domestic supply shock, from about six percent to the MP shock and from about three percent to the exchange rate shock. The overall effect attributed to the transmission of foreign shocks accounts for about 33 percent. For Slovakia, the distribution of the shocks' contribution to output variability differs. The variation in Slovakia's output gap is from about 18 percent due to the domestic demand shock, from about ten percent due to the MP shock, from about three percent due to the supply shock and from about one and half percent due to the exchange rate shock. The variation due to the foreign shock accounts for about 68 percent, a much higher percentage than for Macedonia. In sum, while the most dominant source of variation in the output gap is the preference (demand) shock for Macedonia, the foreign shocks, in sum, are the dominating source for output gap variability in Slovakia, where the domestic demand shock follows.

The most dominant source of shocks for the CPI inflation in Macedonia are the foreign shocks (about 90 percent), followed by the domestic demand shock (about eight percent). In contrast for Slovakia's CPI inflation, the most dominant source of variability is the domestic supply shock (about 41 percent) closely followed by the aggregated impact of foreign shocks.

The variation in Macedonia's interest rate overwhelmingly originates in foreign shocks from about 91 percent and the effect of the domestic shocks in thus marginal. Also, for Slovakia, the effect of foreign shocks on interest rate volatility dominates (about 58 percent), but the domestic demand shock and monetary policy shock contribute significantly as well (about 19 and 15 percent respectively).

The real exchange rate variations for Macedonia could be attributed from about 81 percent to the aggregated foreign shocks, however, the domestic demand shock and the foreign exchange shock account for significant 9.2 and nine percent respectively. While still dominant as the source of exchange rate variations, the foreign shocks account for relatively smaller 57 percent of real exchange rate variation in Slovakia. In addition, the contribution of domestic shocks, most notably the demand and MP shocks, to real exchange rate variability are larger, 29 and 9 percent respectively.

6.1. Shocks Based on Estimated Standard Deviations

We now consider the effect of the sizes of individual structural shocks, based on their estimated standard deviations, in addition to the differing transmission mechanisms in Macedonia and Slovakia. Table 4 shows the computed standard deviations of the simulated variables of interest using the estimated transmission mechanism and structural shock sizes reported in Table 1.

Table 4: Computed Standard Deviations of Simulated Variables Using Estimated S.D.s

Variable	Macedonia	Slovakia

y_d	1.3725	4.1818
pi_c	3.4546	5.2595
i	6.3552	4.9764
q	30.8237	16.5294

The computed standard deviation of the output gap for Macedonia and Slovakia implies higher volatility of the output gap in Slovakia, similar to when the unit shocks were considered (see Table 2). The standard deviation of CPI inflation is higher for Slovakia, in contrast to the results obtained when the unit shocks were considered. Recall that the structural coefficients, including the standard deviation of structural shocks, are mapped to the reduced-form coefficient in a non-linear manner, so the computed standard deviation of the simulated variables of interest can change substantially when moving from unit shocks to one-standard deviation shocks. Note that the e_x size is two times higher for Slovakia while the size of e_d is two times higher for Macedonia. However, in absolute terms the exchange rate shocks for Slovakia is the greatest.[6] The volatility of the simulated interest rate remains higher for Macedonia even when the different sizes of shocks are considered. The same is true for the real exchange rate volatility, although the ratio between the standard deviation for Macedonia and Slovakia dropped to about two from almost three before (see Table 2).

Next, we inspect whether the consideration of the differing sizes of structural shocks have had any material impact on the variance decomposition of the variables of interest – reported in Table 5.

Table 5: Computed Variance Decompositions for Macedonia and Slovakia

	Macedonia					Slovakia				
Variable	**e_y**	**e_x**	**e_d**	**e_mp**	**e_F**	**e_y**	**e_x**	**e_d**	**e_mp**	**e_F**
y_d	29.35	10.7	27.39	30.82	1.75	15.09	15.17	3.1	62.28	4.36
pi_c	23.92	18.5	7.98	27.8	21.79	2.34	10.38	32.89	52.55	1.84
i	17.67	40.82	1.71	17.94	21.86	12.34	1.75	7.84	74.89	3.17
q	13.27	68.13	0.76	8.97	8.89	19.95	23.75	2.95	50.18	3.17

Note: This simulation uses shocks with estimated standard deviation from historical data.

The results in Table 5 for Macedonia suggest that when considering the estimated structural transmission mechanism and the relative sizes of shocks, the variance decomposition for some variables changes considerably in comparison to that reported in Table 3. Namely, the output gap variance is now only from about 30 percent determined by the domestic demand shocks,

[6] The EMEs which are relatively more integrated in the international markets, such as Slovakia compared with Macedonia, are expected to face larger external shocks due to larger movements of capital flows (Caballero and Cowan, 2007).

compared to 45 percent when only differences in the transmission mechanisms are considered (see Table 3). The significance of foreign shocks in determining the output gap variance has declined notably and is now negligible, whereas the share of variance in the output gap due to the MP shock has increased to a percentage similar to that attributed to the demand shock. A comparable change in the variance decomposition can be observed for Slovakia, for which the influence of the demand shock has dropped slightly from about 18 percent (Table 3) to about 15 percent (Table 5). Furthermore, the increase in the influence of the MP shock has increased notably to 62 percent and is potentially the most influential driver of output gap volatility in Slovakia. In addition, the influence of exchange rate shocks on Slovakia's output gap has increased to 15 percent and is similar to that of the demand shock.

The CPI variance decomposition for Macedonia indicates that the influence of the foreign shocks -- the main driver identified in Table 3 – declines markedly when relative sizes of shocks are considered. Table 5 shows that now the biggest drivers of Macedonia's inflation variance are the demand shock (24 percent) and the monetary policy shock (28 percent), along with the aggregated foreign shocks (22 percent). For Slovakia, the share of inflation's variance attributed to the MP shock increases to 52 percent and becomes predominant, with the share attributable to domestic supply shocks remaining in the second place consistently across Tables 3 and 5, at 41 and 33 percent.

The interest rate variance in Macedonia is driven mostly by exchange rate shocks according to results in Table 5 (from 41 percent). While the results in Table 3 pointed to the aggregated foreign shocks as the main drivers, their share in Macedonia's interest rate variance dropped to 20 percent, when we took into account the relative sizes of shocks. For Slovakia, the most influential driver of interest rate variance is the MP shock in Table 5, in comparison with Tables 3. The percentage attributed to the demand shock declines from 19 to 12 percent when relative sizes of the shocks are considered.

Finally, in contrast to the results in Table 3, the real exchange rate variance in Macedonia is mostly driven by the exchange rate shock as opposed to the aggregated foreign shocks. For Slovakia, the main driver of the real exchange rate variance is now the MP shock (from 50 percent) as opposed to the results in Table 3, when the foreign shocks were the main drivers. The demand shock remains significant in influencing real exchange rate variance in Slovakia given the results in Table 3 and 5, from about 29 and 20 percent respectively.

In sum, when considering only the differences in the estimated transmission mechanisms for Macedonia and Slovakia, while abstracting from the effect of the relative sizes of the structural shocks, the aggregated foreign shocks appear to drive most the variance of the domestic variables in both small open economies. In contrast, when the relative sizes of the estimated structural shocks are considered (along with the differing transmission mechanisms), the main drivers of the variance in domestic variables for Macedonia and Slovakia turn out to be different. The main driver of the variance of the domestic variables in Slovakia becomes the monetary policy shock. In contrast, there is no single dominating driver for Macedonia, for which the exchange rate shock, the monetary policy shock and the demand shock are found to be the most important drivers of the domestic variables' volatility.

7. Conclusion

This paper estimated the structural model of Linde *et al.* (2008), using macroeconomic data for Macedonia and Slovakia, and compared the estimated structural parameters and transmission mechanisms, including the sizes of the identified structural shocks, across the two countries. We found that Slovakia has a significantly higher elasticity of intertemporal substitution, the export share in domestic production, and a significantly lower share of imports in consumption and the elasticity of substitution across the domestically produced and imported goods. These differences imply lower sensitivity of the output gap to changes in the real interest rates in Slovakia, and thus weaker credit channel of monetary policy. Slovakia has also been experiencing higher price inertia due to estimated differences concerning production technology and a greater fraction of firms which do not re-optimize their price. The estimated reaction functions of monetary policy, including inflation, the output gap, the euro area interest rate and exchange rate, show Macedonia and Slovakia as inflation targeters. This was expected for Slovakia which has applied inflation targeting as the official monetary policy regime. However, the result for Macedonia contradicts its official monetary policy regime of pegged exchange rate, and shows Macedonia as a relatively more conservative inflation targeter compared to Slovakia.

The estimated differences in structural parameters imply differing transmission mechanism for Macedonia and Slovakia, including the response of the CPI inflation to the demand shock; the response of the output gap to the supply shock; the response of the real exchange rate to the monetary policy shock; and the inflation response to the exchange rate shock. When considering only the differences in the estimated transmission mechanisms for Macedonia and Slovakia, and abstracting from the effect of the relative sizes of structural shocks, the aggregated foreign shocks are responsible for most of the variance in domestic variables in Macedonia and Slovakia. However, when the differing sizes of structural shocks are considered in addition, the variance of domestic variables in Slovakia is most influenced by monetary policy shocks. There is no single dominating shock explaining the volatility of Macedonia's macroeconomic variables, where the exchange rate shock, the monetary policy shock and the demand shock are jointly important in determining the variables' volatility. Based on simulations from the estimated model, Macedonia shows lower output gap and inflation volatility than Slovakia, at the cost of higher volatility in the interest rate and real exchange rate, and thus possibly financial markets. Nevertheless, these observations can change gradually with the progressing transition process in Macedonia and its further integration into international markets.

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Appendix A

A1. Outline of the Optimization Problem of Households

Households maximize they utility function described in (A1 and A2) by choosing their current consumption C_t^j, and holdings of one-period domestic, B_t^j, and foreign bonds, $B_t^{f,j}$**,** under the constraint described in (A3).

$$\max_{C_t^j, B_t^j, B_t^{f\ j}} \mathrm{E}_t \sum_{k=0}^{\infty} \beta^k u\left(C_{t+k}^j\right) \qquad \text{(A1.1)}$$

where β is the discount factor, and household preferences are assumed to show external habit formation of the 'Catching up with the Joneses' type (see Abel,1990; Smets and Wouters, 2003) so that their individual utility from consumption is assumed to depend on past aggregate consumption. In addition, their utility is subject to a preference shock Υ_t. σ is a risk aversion parameter and h is a habit persistence parameter.

$$u\left(C_t^j\right) = \Upsilon_t \frac{\left(C_t^j - hC_{t-1}\right)^{1-\sigma}}{1-\sigma} \qquad \text{(A1.2)}$$

The composite consumption index C_t consists of bundles of domestic and imported goods and is defined as:

$$C_t = \left[\left(1-\omega_m\right)^{1/\eta}\left(C_t^d\right)^{(\eta-1)/\eta} + \left(\omega_m\right)^{1/\eta}\left(C_t^m\right)^{(\eta-1)/\eta}\right]^{\eta/(\eta-1)} \qquad \text{(A1.3)}$$

where ω_m is the share of imports in consumption, and η is the elasticity of substitution across the two categories of goods. And, the bundles of domestic C_t^d and imported C_t^m goods are defined by

$$C_t^d = \left[\int_0^1 \left(C_t^{d,i}\right)^{(\eta_d-1)/\eta_d} di\right]^{\eta_d/(\eta_d-1)} \text{ and } C_t^m = \left[\int_0^1 \left(C_t^{m,i}\right)^{(\eta_m-1)/\eta_m} di\right]^{\eta_m/(\eta_m-1)} \qquad \text{(A1.4)}$$

where η_d and η_m are the elasticities of substitution across goods.

Households finance their consumption and purchases of domestic and foreign bonds through proceeds from domestic and foreign bond holdings and their share of aggregate real profits.

$$C_t^j + \frac{B_t^j}{(1+i_t)P_t^c} + \frac{S_t B_t^{f,j}}{\left(1+i_t^f\right)\Phi(A_t)P_t^c} = \frac{B_{t-1}^j}{P_t^c} + \frac{S_t B_{t-1}^{f\ j}}{P_t^c} + X_t^j \qquad \text{(A1.5)}$$

S_t is the nominal exchange rate (the domestic currency price of foreign currency); X_t^j is household *j*'s share of aggregate real profits in the domestic economy (the sum of profits in the domestic sector and in the importing sector); and where domestic bonds give the gross return $(1+i_t)$ and foreign bonds give the adjusted return $(1+i_t^f)\Phi(A_t)$. The term $\Phi(A_t)$, a premium on foreign bond holdings is a function of the real aggregate net foreign asset position of the domestic economy $A_t \equiv S_t B_t^f / P_t^c$. The function $\Phi(A_t)$ captures the costs for domestic households of undertaking positions in the international and financial market, and is assumed to follow $\Phi(A_t) = e^{-\phi A_t}$, where $\phi > 0$, so $\Phi(A_t)$ is strictly decreasing in A_t and $\Phi(0) = 1$.

A2. Outline of the Optimization Problem of Firms in the Domestic Sector

In the absence of adjustment costs, the domestic firm *i* would choose prices for the domestic and foreign markets (denoted $\hat{P}_t^{d,i}$ etc.) to maximize profits:

$$\max_{\hat{P}^{d,i},\hat{P}^{df,i}} \hat{P}_t^{d,i} C_t^{d,i} + S_t \hat{P}_t^{df,i} C_t^{df,i} - P_t^z Z_t^i \tag{A2.1}$$

subject to the production function

$$Y_t^i = \left(Z_t^i\right)^{1-\theta} = \left[\left(Z_t^{d,i}\right)^{1-\kappa}\left(Z_t^{m,i}\right)^{\kappa}\right]^{1-\theta}, \tag{A2.2}$$

which assumes that firm *i* in the domestic sector produces a differentiated good Y_t^i from intermediate domestic and imported inputs $Z_t^{d,i}$ and $Z_t^{m,i}$ according the production function in (A2.2), where κ is the share of imports in intermediate goods, and θ is a technology parameter. And, subject to the demand functions in the domestic and foreign markets

$$C_t^{d,j} = \left[\frac{P_t^{d,j}}{P_t^d}\right]^{-\eta_d} C_t^d \quad \text{and} \quad C_t^{df,j} = \left[\frac{P_t^{df,j}}{P_t^{df}}\right]^{-\eta_d} C_t^{df} \tag{A2.2}$$

Solution to this problem then yields the optimal flexible price in the domestic market.

A3. Outline of the Optimization Problem of Firms in the Monopolistically Competitive Imported Goods Sector

In the import sector, firm *i* maximizes:

$$\max_{\hat{P}^{m,i}} \left(\hat{P}_t^{m,i} - S_t P_t^{zf}\right) C_t^{m,i} \tag{A3.1}$$

where P_t^{zf} is marginal cost in the foreign economy, subject to the demand function,

$$C_t^{m,j} = \left[\frac{P_t^{m,j}}{P_t^m}\right]^{-\eta_m} C_t^m . \qquad \text{(A3.2)}$$

This yields the optimal flexible price in the imported goods sector.

A4. Outline of the Price-Setting Behavior of Firms

In the face of quadratic adjustment costs, those firms in sector *j* (*j*=*d, m*) that reoptimize in each period minimize the expected log deviation of the price from the optimal flexible price, given the adjustment cost γ_j:

$$\min_{p_t^{opt,j}} E_t \sum_{s=0}^{\infty} \beta^s \left\{ \left(p_{t+s}^{opt,j} - \hat{p}_{t+s}^j \right)^2 + \gamma_j \left(p_{t+s}^{opt,j} - \hat{p}_{t+s-1}^j \right)^2 \right\} \qquad \text{(A4.1)}$$

In each sector *j* a fraction α_j of firms does not reoptimize their price, but instead use a mechanical rule of thumb whereby prices are set to equal the observed aggregate price in the previous period adjusted for the previous period's inflation rate in that sector:

$$p_t^{rule,j} = p_{t-1}^j + \pi_{t-1}^j \qquad \text{(A4.2)}$$

The inflation rate in sector *j* is then given by

$$\pi_t^j = \left(1-\alpha_j\right)\pi_t^{opt,j} + \alpha_j \pi_t^{rule,j} \qquad \text{(A4.2)}$$

Appendix B – Definition of Composite Parameters

B1. Aggregate Demand Curve – Equation (1)

$$a_y = \frac{1}{1+h};\ a_r = -\frac{(1-h)(1-\omega_x)}{(1+h)\sigma};\ a_{\tau f1} = \frac{h\omega_x\eta}{1+h};\ a_{\tau f2} = -\omega_x\eta;\ a_{\tau f3} = \frac{\omega_x\eta}{1+h}$$

$$a_{\tau 1} = -\frac{h\eta\omega_m(1-\omega_x)}{1+h};\ a_{\tau 2} = -\frac{\omega_m(1-\omega_x)(1-h-\eta\sigma-h\eta\sigma)}{(1+h)\sigma};\ \ a_{\tau 3} = \frac{\omega_m(1-h-\eta\sigma)(1-\omega_x)}{(1+h)\sigma}$$

$$a_{yf1} = -\frac{h\omega_x\chi_f}{1+h};\ a_{yf2} = \omega_x\chi_f;\ a_{yf3} = -\frac{\omega_x\chi_f}{1+h};\ u_t^y = \frac{(1-h)(1-\omega_x)}{(1+h)\sigma}\left[\upsilon_t - \mathrm{E}_t\upsilon_{t+1}\right]$$

where the parameter χ_f is the income elasticity of foreign consumption, ω_x is the export share of domestic production, and $\upsilon_t \equiv \log \Upsilon_t$.

B2. The Net Foreign Assets and Real Profit Equations (3) and (4)

$$d_a = \frac{1}{\beta}\text{;}\ \ d_y = -\frac{\Gamma_1}{\beta(1-\omega_x)\left[1+(1-\omega_m)\Gamma_1\right]}\Gamma_2^{(\theta-1)/\theta}\text{;}\ \ d_x = \frac{\Gamma_1}{\beta\left[1+(1-\omega_m)\Gamma_1\right]}\Gamma_2^{(\theta-1)/\theta}$$

$$d_\tau = \frac{\eta\omega_m\Gamma_1}{\beta\left[1+(1-\omega_m)\Gamma_1\right]}\Gamma_2^{(\theta-1)/\theta}\text{;}\ \ d_{\tau f} = -\frac{\eta\omega_x\Gamma_1}{\beta(1-\omega_x)\left[1+(1-\omega_m)\Gamma_1\right]}\Gamma_2^{(\theta-1)/\theta}\text{;}$$

$$d_{yf} = -\frac{\chi_f\omega_x\Gamma_1}{\beta(1-\omega_x)\left[1+(1-\omega_m)\Gamma_1\right]}\Gamma_2^{(\theta-1)/\theta}\text{;}$$

$$\Gamma_1 \equiv \frac{\eta_m(1-\theta+\eta_d\theta)}{\eta_d\eta_m-\eta_m(1-\theta+\eta_d\theta)(1-\omega_m)-\omega_m\eta_d}\text{;}\ \ \Gamma_2 \equiv \frac{\eta_d}{(\eta_d-1)(1-\theta)(1-\kappa)^{1-\kappa}\kappa^\kappa}$$

$$e_y = \frac{\eta_m-(\eta_m-1)\omega_m}{\eta_m(1-\omega_x)} - \frac{\eta_d-1}{\eta_d}\left[1-\omega_m+\frac{1}{\Gamma_1}\right]\text{;}\ \ e_\tau = -\frac{\eta\omega_m}{\eta_m} - \frac{\kappa(\eta_d-1)(1-\theta)}{\eta_d}\left[1-\omega_m+\frac{1}{\Gamma_1}\right]$$

$$e_{\tau f} = \frac{(\eta_m-1)\omega_m}{\eta_m} + \frac{\eta\omega_x\left[\eta_m-(\eta_m-1)\omega_m\right]}{\eta_m(1-\omega_x)} - \frac{\eta}{\Gamma_1}\text{;}\ \ e_{yf} = -\frac{\chi_f\omega_x\left[\eta_m-(\eta_m-1)\omega_m\right]}{\eta_m(1-\omega_x)} + \frac{\chi_f}{\Gamma_1}$$

B3. Aggregate Supply Curves – Equations (7) and (8)

$$b_{\pi 1} = \beta\gamma_d\Psi_d\text{;}\ \ b_{\pi 2} = \alpha_d(1+2\gamma_d+\beta\gamma_d)\Psi_d,\ \ b_{\pi 3} = -\alpha_d\gamma_d\Psi_d\ \ b_y = \frac{\theta(1-\alpha_d)}{1-\theta}\Psi_d$$

$$b_\tau = \kappa(1-\alpha_d)\Psi_d$$

$$c_{\pi 1} = \beta\gamma_m\Psi_m\text{;}\ \ c_{\pi 2} = \alpha_m(1+2\gamma_m+\beta\gamma_m)\Psi_m\text{;}\ \ c_{\pi 3} = -\alpha_m\gamma_m\Psi_m\text{;}\ \ c_\tau = -(1-\alpha_m)\Psi_m$$

$$\Psi_j = \left[\alpha_j+\gamma_j(1+2\beta\alpha_j)\right]^{-1},\ \ j = d,m$$

Appendix C – Estimated VAR Coefficients for the Euro Area

Table A1: Estimated VAR Coefficients for the Euro Area

Parameter	Estimate	St. D.	t-stat.
apif	-0.2239	0.1727	1.2962
aif	0.0075	0.0953	0.0784
ayf	0.8439	0.1491	5.6602
rho_uyf	0.1603	0.2026	0.7913
bpif	0.6499	0.2824	2.3014
bif	0.0824	0.0883	0.9326
byf	0.0954	0.0820	1.1638
rho_uf	0.0279	0.3942	0.0708
cpif	-0.3410	0.3162	1.0784
cif	0.9776	0.1176	8.3129
cyf	0.1560	0.0909	1.7162
rho_uif	0.4215	0.4104	1.0269
std(e_yf)	0.4868	0.0475	10.2415
std(e_f)	0.3026	0.0298	10.1697
std(e_if)	0.3638	0.0355	10.2377
Log Likelihood		**75.422328**	

Note: estimated by the maximum-likelihood method