Real Exchange Rate Dynamics in the New Member States of the EU – Run-up to the Euro

by

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SUMMARY

This dissertation contributes to the literature addressing the euro adoption by the New Member States (NMSs) of the European Union by proposing a definition of real convergence based on real exchange rate (RER) dynamics. As fluctuations in RER represent deviations from purchasing power parity (PPP), the thesis also adds to the literature on PPP theory. Finally, by proposing basic and extended small open economy dynamic stochastic general equilibrium international real business cycle (SOE-DSGE-IRBC) models of RER determinants for the NMSs, it fills a gap that has hitherto existed in the literature.

The analysis of RER dynamics is conducted on two levels: empirical and theoretical. On the empirical level, the scale of RER dynamics in the NMSs is measured. Factors contributing to these dynamics are identified. Particular attention is drawn towards the factors which could account for the recorded appreciation of RER in these countries since the early 1990s. On a theoretical level, variants of the SOE-DSGE-IRBC model of RER determinants for a typical NMS are developed.

The findings of Chapter 1 show that the univariate variance analysis accurately measures real convergence in the analysed countries. The results also indicate that at present, only Estonia and Slovenia (ex post) are ready to adopt the euro. The basic SOE model of Chapter 2, unlike its expanded version of Chapter 3, is only able to roughly match the moments of the Polish data. Therefore, its findings provide insights into the theoretical 'puzzle' of RER volatility and its persistence. The expanded model results show that productivity shocks to the *non-traded* sector are the main cause of price differentials between Poland and the euro area. This is in contrast to the two competing hypotheses that either productivity or quality improvements in the tradable sector are the main source of real exchange rate appreciation in this country.

INTRODUCTION

This thesis analyses real exchange rate (RER) dynamics of the New Member States (NMSs) of the European Union (EU), and explores the implications of these dynamics for the entry of the NMSs into the eurozone. Analysis of RER dynamics is of course not a new topic. It goes back to Cassel's (1918) analysis of purchasing power parity (PPP). It has given rise to a rich body of literature, among the most interesting aspects of which is the 'puzzle' of why fluctuations in real exchange rates are often very large and persistent compared with other macroeconomic variables, such as output for instance. This dissertation contributes to the literature on PPP on two levels: empirical and theoretical. On an empirical level, it attempts to measure the scale of the RER dynamics (with respect to the euro) in the NMSs of the EU, and to identify the factors contributing to these dynamics. On a theoretical level, and motivated by the empirical findings, it develops variants of the small open economy dynamic stochastic general equilibrium international business cycle (SOE-DSGE-IRBC) model to describe the RER determinants for a typical NMS of the EU – an approach hitherto absent in the literature for the EU NMSs. In so doing it helps to shed some light on what lies behind the 'puzzle' of large and persistent RER fluctuations.

The relevance of RER dynamics in the context of the euro adoption by EU NMSs is better understood once the movements of the RER are viewed as an indicator of underlying economic conditions between a particular NMS and the eurozone. In this thesis it is argued that the scale of RER volatility (against the euro) can be a useful measure of the degree of real convergence understood as the degree of symmetry between these two economic zones. This is because the lower the degree of RER volatility due to real shocks, the greater is the extent of adjustment mechanisms at work other than the nominal exchange rate, and/or the lower is the exposure of the NMSs to asymmetric shocks, and/or the greater is the degree of symmetric monetary policy responses between the respective NMSs and the eurozone in response to symmetric shocks. Because in the European Monetary Union (EMU) (and any common currency area) the set of policy tools that can be used to mitigate the impact of arising asymmetries, is considerably reduced, the degree of asymmetry between the NMSs and the eurozone represents the cost of the euro adoption. Consequently, since *a less volatile RER* indicates greater symmetry between economic zones*, it also reduces the scope for monetary and exchange rate independence*.

The analysis of RER dynamics in the NMSs proposed in this dissertation is relevant both in the run-up to accession to the eurozone of these countries, and after accession has taken place. If the average eurozone inflation level at the launch of the expanded euro area is assumed to reflect an equilibrium, the degree of fluctuations of the intra eurozone real exchange rates (i.e. inflation dispersion) can be taken to reflect the degree of asymmetry between the eurozone average and its individual member states. As documented in the literature, these asymmetries are not negligible among the current eurozone members (see for example De Grauwe and Skudelny (2000), Andrés et al. (2006) or Altissimo et al. (2005)). Given that the NMSs have much lower price and income levels than the first eurozone entrants, it is unlikely that these asymmetries are going to disappear once the fixed nominal exchange rate (the euro) is introduced in these countries.

Some have argued that one need not worry about large asymmetries between economies creating a common currency region (or thereafter). Since the RER is by definition the relative price of domestic and foreign production, changes to that price can play a stabilizing role even *within* a currency union (i.e. they can influence the balance of supply and demand between domestic and foreign goods and services). However, this is not necessarily the issue. The issue is not that the RER can adjust, but the different ways in which real exchange rates adjust inside and outside of a currency zone.

The variation in the channels of possible adjustments in and outside a common currency area has different implications with different challenges. For example, a RER appreciation is needed in the presence of excess demand for home production in order to restore equilibrium. Under both fixed and flexible exchange rate regimes the expenditure-switching mechanism eventually restores the balance by re-directing demand towards foreign production and supply towards domestic markets (as predicted by Mundell-Fleming-Dornbusch type models). The adjustment mechanism however depends on the exchange rate regime in place. Under the flexible regime, the required appreciation may happen (fully or partially) via movements in the nominal exchange rate. In the situation when the nominal exchange rate cannot adjust, necessarily, all the pressure is put on the domestic price level, which, in this case, must increase, causing domestic inflation. Likewise, if a shock to external demand is negative, in the absence of nominal exchange rate adjustments, without immediate improvements in productivity, RER depreciation will have to be accommodated by declining wages and prices. This will result in unemployment and possible political tensions. Additionally, given frictions in prices and wages and in the absence of other flexible adjustment mechanisms, positive and negative external demand shocks can result in a prolonged period of RER misalignment and persistent regional disparities. Depending on the direction of the shock this situation could have negative implications for countries' terms-of-trade (i.e., a drop in the price of commodities which is not accompanied by the immediate price change results in exporters' losses).

Of course there are also other types of shocks, such as internal demand shocks, which are probably better tackled with fiscal instruments. Nonetheless, fiscal policy is not always easily/promptly available, for political reasons. Besides, the choice of the adjustment mechanism depends on the nature of the shock and internal and external conditions. For instance, for catching-up economies like the NMSs, the right response to macroeconomic imbalances stemming from increases in internal demand might be to accept higher inflation accompanied by current and trade account deficit in anticipation of future surpluses as well as increases in real income, and not a fiscal contraction. Also, since the NMSs have high growth potential, they may run into the problem of overheating after reaching the equilibrium level of economic activity. To slow down, wage increases may be needed (see Blanchard (2001) on the Irish and Spanish case)[1].

This is not to say that RER volatility is necessarily a result of undesirable shocks, in which corrections are desirable. It can be an equilibrium phenomenon, a result of

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[1] One can argue (in line with R. McKinnon (2000)) that if macroeconomic shocks were themselves induced by poor policies, creating a currency area with another country or a group of countries would minimize those shocks (for example by imposing fiscal discipline). Nevertheless, the more similar the structures of economies wishing to formulate a currency union, the lower the likelihood that common shocks will have asymmetric rather than symmetric effects.

improvements in the tradable sector productivity (i.e., the Harrod-Balassa-Samuelson (HBS) effect), improvements in equilibrium employment, capital accumulation, liberalisation of prices, or increases in the initially undervalued exchange rates, to name a few. These trends have been observed already (see Błaszkiewicz, et al. (2005)) and are likely to continue for quite some time in the NMSs, since these economies are characterised by relatively low income levels. If underlying changes in the domestic price level in these countries were only to mean higher steady state inflation and gradually appreciating equilibrium real exchange rates, then the appropriate policy would be again to accept them, since they are necessary for achieving higher standards of living.

Overall, however, managing large real external or internal imbalances in countries with sizable asymmetric real shocks is likely to prove to be difficult, especially during the mandatory Exchange Rate Mechanism II (ERMII) period prior to the euro adoption. This is because the fulfilment of the Maastricht criteria requires simultaneous stabilisation of inflation and the nominal exchange rate, as well as a balanced budget. Meeting these conditions can be further complicated if they are coupled with large and volatile capital flows and credit booms. Under a common monetary policy, unless these asymmetries are absorbed, major trend movements in domestic wages and price levels can be expected. Clearly, where this is the case, there is a danger that monetary conditions set by the European Central Bank (ECB) will be too loose for the individual NMSs and thus not optimal. Moreover, assuming that the eurozone will have a fairly constant price level, and given that the real convergence process can be expected to continue for quite some time, large asymmetric changes in relative prices could have negative implications for price competitiveness[2]. Additionally, as shown by Canzoneri et al. (2008), who studied the interactions of twelve separate fiscal policies and the common monetary policy in the euro zone, the smaller eurozone countries seem to be at a particular disadvantage when compared with bigger members when the costs of asynchronised business

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[2] It is often argued that fixed exchange rates are beneficial for trade (see Rose (2000), Jeanne and Rose, (2002)). But trading companies still remain subject to the RER changes. Despite the fact that in the currency union they have more time to adjust to price changes (i.e., domestic prices tend to move more slowly than nominal exchange rates), volatile real exchange rates do change price competitiveness for exporting and importing companies.

cycles are calculated. This is because inflation rates in the larger countries show higher correlation with the aggregate euro area inflation to which the ECB reacts. Their calculations show that the welfare costs of business cycles can be up to four times higher in an "average-size" EMU country (to which the NMSs will be classified) than in a "large" one.

From the above discussion, and given that the convergence process is already underway, the importance of the evaluation of the RER dynamics in the NMSs is clear. Even if real convergence is not a Maastricht criteria, it should be an important part of the analysis of the timing of the ERMII/EMU accession and should be an integral part of ERMII/ EMU monitoring and decision making. Understanding RER dynamics is also important from the point of view of equilibrium exchange rate analysis. Once NMSs are in the eurozone, the analysis of their exchange rate dynamics will help identify the need for structural adjustments and should inform the conduct of a macroeconomic policy.

Chapter 1 of this thesis further discusses the importance of RER variability for the euro decision making process, proposes a definition of real convergence in terms of RER volatility, and sets out an analysis of the degree of this convergence between the selected NMSs and the euro area. As a part of the analysis, the degree of real convergence in the NMSs is compared with the degree of real convergence achieved by the selected Old Member States (OMSs) of the EU in the onset of the euro introduction. To quantify RER volatility in the New and Old Member States of the EU, as well as to assess whether the NMSs are converging over time in real terms, a two-step variance analysis is performed. The two-step variance analysis is necessary as there exists no uniform econometric methodology which would allow for an adequate measure of RER volatility (and thus the measure of real convergence) due to real shocks only. There are various ways the volatility can be measured. In this study, in step one, the univariate variance analysis of real exchange rates in countries of interest is performed. The AR(p) and AR(p)-GARCH(p,q) econometric methodologies are used to measure the degree of RER volatility[3]. To separate and

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[3] AR(p) refers to the autoregressive model of order p. GARCH(p,q) refers to generalized autoregressive conditional heteroskedasticity model of order p and q (p is the order of autoregressive

measure the magnitude of real and nominal components in real exchange rate movements, in step two, a bivariate variance analysis is conducted. It utilises a structural vector autoregression methodology with a Blanchard and Quah (1989) decomposition (BQ-SVAR). Given that BQ-SVAR methodology cannot measure the overall degree of RER volatility, in the context of the proposed definition of real convergence, it necessarily complements the univariate analysis. Moreover, to the extent that giving up an independent monetary and exchange rate policy can constitute a cost of the euro adoption, a BQ-SVAR analysis also facilities the assessment of the role of the nominal exchange rate in the NMSs in accommodating real asymmetric shocks. The results of the two-step variance analysis indicate that: (i) real asymmetric shocks are significant when compared with those experienced by the poorer Old Member States of the European Union in their accession to the eurozone; (ii) nominal exchange rates, in general, do play a stabilising role in the NMSs; and that (iii) nominal shocks, on average, do not move real exchange rates. Therefore, based on the analysis conducted in this chapter, it appears that among the NMSs, at present, only Estonia and Slovenia (already in the eurozone) are ready to give up monetary and exchange rate independence.

Chapters 2 and 3 present an analysis of RER dynamics in the SOE-DSGE framework. A special emphasis is put on investigating the sources of RER appreciation recorded by the NMSs since the early 1990s (see Figure A.1.1 in Annex A.1). To strengthen the theoretical investigation, more data analysis on the possible RER determinants is provided in both chapters. Although this part of the dissertation focuses on Poland (i.e. the additional empirical investigation and the models' calibration are done for Poland), given structural similarities among the NMSs and the stylised character of proposed models, they have much broader application.

The objective of Chapter 2 is two-fold. First, given Chapter 1's findings that nominal shocks, on average, do not move real exchange rates in the NMSs, the chapter examines the nature of *real* determinants of RER movements in these countries. This

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GARCH terms, and q is the order of moving average autoregressive conditional heteroskedasticity (ARCH) terms).

is important, as – given the existing real asymmetries - these real determinants need to be better understood if progress in real convergence is to be achieved. Second, Chapter 2 seeks to match the RER variability and its appreciation observed in the NMSs. To meet these objectives, a basic, one sector, flexible price and wage SOE-DSGE IRBC model with monopolistic competition and complete market is developed[4].

The one sector model is used for two reasons. First, in his influential work, Engel (1999) demonstrated that the bulk of RER movements can be accounted for by the movements of relative prices of tradable goods between countries – the so-called external real exchange rate channel. As pointed out by Vilagi (2005), because of market segmentation, the lack of empirical support for PPP, and the correlation between nominal and real exchange rates, this is the more traditional approach to modelling real exchange rate misalignments within the DSGE framework (or more precisely, New Open Economy Macroeconomics (NOEM)). Second, even if in the NMSs appreciating real exchange rates are often discussed in the context of the HBS effect (i.e. the internal RER movements), the empirical relevance of this effect is mixed (see Egert (2002), Błaszkiewicz, et al. (2005), Mihaljek and Klau (2004), Wagner (2005))[5]. Moreover, as will be shown in the body of Chapter 2, there is evidence of strong export performance in the NMSs, which is combined with terms-of-trade improvements, increased export unit values and quantities exported. These trends suggest that in the NMSs the external and not internal RER may be more important in real exchange rate developments. In particular, the observed trends point to the quality factor as an important determinant of RER improvements (see also Egert and Lommatzsch (2004), Lommatzsch and Tober (2004), Hanousek and Filer (2004) or Broeck and Slok (2006) discussed in Chapter 2).

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[4] The reasons why the models of Chapter 2 and 3 do not include nominal rigidities or monetary disturbances is discussed in the body of Chapter 2.

[5] For the detailed exposition of the HBS effect see Błaszkiewicz et al. (2005). In short, the HBS effect predicts that productivity improvements in the tradable sector, via wage equalisation, lead to price increases in the nontradable sector. This appreciates the ratio of the domestic prices of tradables to non-tradables relative to the same ratio abroad (the so-called internal real exchange rate) and leads to the overall real exchange rate appreciation.

To the extent that quality changes might be responsible for RER dynamics in the NMSs, the model put forward in Chapter 2 includes home bias in consumption and exogenous quality factor. A home bias channel captures the shift in consumer preferences towards higher quality products and thus looks at the effect of quality changes on the RER from the demand side. An exogenous quality factor captures the supply side. The home bias channel in the one sector, flexible price, model is crucial as it breaks PPP, allowing for real exchange rate fluctuations. It also diminishes the expenditure-switching mechanism, adding to real exchange rate persistence.

The model developed in Chapter 2 and calibrated to the Polish economy (chosen as a representative NMS for the purposes of calibration) shows that the main RER determinants are quality and productivity shocks (although a consumption preference shock also matters). The observed RER appreciation (as evident for Poland and other NMSs) is indeed possible when the economy is hit by a shock that improves the quality of domestically produced goods. Positive changes to productivity bring about a depreciation of the real exchange rate. However, the fit of the model in terms of the key moments of the Polish data, depends on the elasticity of substitution between home and foreign tradable goods. The model best matches the data when the value of this elasticity is very low. Surprisingly, the basic SOE-DSGE IRBC model performs reasonably well in delivering a persistent RER.

Chapter 3 builds on the SOE-DSGE IRBC model developed in Chapter 2 by adding a number of additional mechanisms to improve the model performance in terms of matching the moments of the Polish data. These mechanisms include a nontradable sector, a distribution sector and incomplete risk-sharing. The nontradable sector is integrated into the model because even if the empirical significance of the HBS effect in real exchange rate movements in the NMSs is mixed, the studies cited above do agree that it is not insignificant. Moreover, as will be shown in the body of the chapter, the limited relevance of the HBS effect in the NMSs may be related to measurement problems. Also, Burstein et al. (2005) point out that Engel's (1999) measures do not separate the distribution component of tradable good prices. When these authors adjust traded goods prices for a tradable component, they find that around 50 percent of real exchange rate movements should be attributable to the movements in the relative price of nontraded goods. Therefore, adding not only the nontradable but also distribution sector into the model is of relevance. The distribution sector also allows deviations from the law of one price for baskets of goods that are traded. This is important as these deviations play a large role in real exchange rate fluctuations (see, for example, Betts and Kehoe (2006)). Finally, incomplete risk-sharing allows for another channel of possible real exchange rate fluctuations, namely the impact of international payments on the real exchange rate (e.g. Corsetti et al. (2007), Benigno and Theonissen (2006), Selaive and Tuesta (2006)).

The expanded model is able to account for the main features of the Polish data and captures the dynamics of RER movements. The model's ability to replicate the RER volatility and persistence observed in the Polish data, without resorting to nominal rigidities and monetary shocks, confirms the importance of real factors in driving real exchange rates in Poland (and other NMSs). Moreover, this is achieved without using unrealistically low values of elasticity of substitution between home and foreign tradable goods.

Also, in Chapter 3, the model responds to a positive tradable productivity shock that generates the RER appreciation consistent with the HBS theory and positive wealth effects[6]. Capturing the HBS-like effect in the two-sector DSGE framework is not an easy task. This is because, in this type of model, a positive productivity shock typically causes a terms-of-trade depreciation, which offsets an appreciation caused by the HBS effect (or HBS and positive wealth effects if markets are incomplete). To the author's best knowledge, there are no models which are able to show this in the small open economy framework – the contribution of this chapter. It is also shown, however, that the RER appreciation in response to the positive tradable productivity shocks depends on the value of elasticity of substitution between domestic and foreign tradable goods *and* on the value of the parameter governing bond holding costs. The value of the parameter governing bond holding costs is also a decisive

[6] Note that for the HBS effect to hold various assumptions must be satisfied. For example, the law of one price (LOOP) must hold, sectoral wages must equalize, domestic and foreign tradable goods should be close substitutes, etc. Unless these are met, what is often called the HBS effect should be understood as the impact of a positive productivity shock in the tradable sector on the internal real exchange rate.

factor in generating RER appreciation in response to the quality shock, i.e., RER appreciates only when these costs are low. To this end, the chapter's findings point towards the importance of the current account channel in RER modelling. Nonetheless, when variance decomposition is performed, the results indicate that neither asymmetric tradable productivity nor quality shocks account for the RER movements in Poland. Instead, as in Altissimo et al. (2005), the main determinants of RER movements are nontradable productivity shocks.

CHAPTER 1

REAL EXCHANGE RATE VOLATILITY: A MEASURE OF REAL CONVERGENCE IN THE CENTRAL AND EASTERN EUROPEAN EURO AREA ACCESSION COUNTRIES

1.1 INTRODUCTION

In 2004 eight Central and Eastern European Countries acceded to the European Union and at the same time became active members of the third stage of the EMU[7]. By doing so, they committed to participate in the ERMII), and eventually adopt a common European currency, the euro. The basis on which these countries time their accession to the ERMII and adopt the euro is of considerable policy importance, and the focus of this chapter.

Under the Maastricht Treaty, the binding criteria for these eight NMSs into the eurozone are exclusively described in nominal terms[8]. However, the fulfilment of Maastricht criteria by no means ensures that the NMSs will enjoy the net benefits of the monetary union. The extent to which the NMSs will benefit from giving up their monetary and exchange rate independence, in addition to the broader issue of the sound functioning of the enlarged eurozone, is generally discussed in terms of *real* factors, in particular, the degree of real convergence between the NMSs and the participating euro area countries.

This chapter proposes a definition of real convergence in terms of real exchange rate volatility and sets out an analysis of the degree of this convergence between the selected NMSs and the euro area. As a part of the analysis, the degree of real convergence in the NMSs is compared with the degree of real convergence achieved

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[7] These were the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic and Slovenia. Although during the time of writing Slovakia and Slovenia joined the eurozone (in January 2009 and January 2007, respectively), they were left in the sample for comparative purposes.
[8] Maastricht criteria relate to the nominal exchange rate, the budget, public debt, inflation rate and long-term interest rates.

by the selected OMSs of the EU at the onset of the euro introduction. To quantify RER volatility in the New and Old Member States of the EU, as well as to assess whether the NMSs are converging over time in real terms, a two-step variance analysis is performed. The two-step variance analysis is necessary as there exists no uniform econometric methodology which would allow for the adequate measure of RER volatility (and thus the measure of real convergence) due to real shocks only. There are various ways the volatility can be measured. In this study, in step one, the univariate variance analysis of real exchange rates in countries of interest is performed. The AR(p) and AR(p)-GARCH(p,q) econometric methodologies are used to measure the degree of RER volatility. To separate and measure the magnitude of real and nominal components in real exchange rate movements, in step two, a bivariate variance analysis is conducted. It utilises a structural vector autoregression methodology with a Blanchard and Quah (1989) decomposition. Given that BQ-SVAR methodology cannot measure the overall degree of RER volatility, in the context of the proposed definition of real convergence, it necessarily complements the univariate analysis. Moreover, to the extent that giving up an independent monetary and exchange rate policy can constitute a cost of the euro adoption, a BQ-SVAR analysis also facilities an assessment of the role of the nominal exchange rate in the NMSs in accommodating real asymmetric shocks. The results indicate that: (i) real asymmetric shocks are significant when compared with those experienced by the poorer OMSs of the European Union in their accession to the eurozone; (ii) nominal exchange rates, in general, do play a stabilising role in the NMSs; and that (iii) nominal shocks, on average, do not move real exchange rates. Based on the analysis conducted in this chapter, it appears that among the NMSs, at present, only Estonia and Slovenia (ex post) are ready to give up monetary and exchange rate independence.

The remainder of the chapter is organised as follows: Part 1.2 proposes the novel definition of real convergence, explains its usefulness as a measure of the degree of real convergence in the NMSs, discusses its pros and cons and finally explains the econometric techniques used to measure it. Part 1.3 analyses the choice of the sample and data properties, including recent developments of nominal and real exchange rates, as well as prices in the NMSs, the evolution of exchange rate regimes, and data integration properties. Part 1.4 sets out and explains methodologies utilised in the univariate estimation of nominal and real exchange rate variances, as well as in the BQ-SVAR model, which is used to identify two structural shocks (i.e., temporary and permanent). Part 1.5 presents the results. Part 1.6 concludes.

1.2 REAL CONVERGENCE: DEFINITION AND MEASUREMENT

There is no generally accepted indicator of real convergence. The European Commission itself, in various contexts, refers to such indicators as the balance of payment position, and to financial and product market integration (Convergence Report 2004). Other research papers (Frankel (2004), Fidrmuc and Korhonen (2004), Kočenda et. al (2006)) focus on narrowing gaps of productivity or real income between respective countries and the euro area average, or concentrate on the correlation of business cycles.

This chapter proposes a definition of real convergence which is based on real exchange rate volatility, i.e., it measures the degree of real convergence between a particular NMS and the eurozone in terms of real exchange rate variances (standard deviations). These variances are then compared with the averages estimated for the selected group of OMS in years preceding the creation of the eurozone. While real exchange rate volatility analysis is not new, and in the context of optimal currency areas goes back to Vaubel (1976, 1978), to the best of the author's knowledge it has not yet been explicitly applied as a measure of real convergence.

What makes the scale of real exchange rate volatility a useful measure of the degree of real convergence? Real exchange rate volatility reflects underlying economic conditions in a number of ways. Under the assumptions of price and wage rigidity, the magnitude of real exchange rate volatility between a particular NMS and the eurozone captures:

- The extent to which flexible adjustment mechanisms affecting relative prices exist in that NMS, other than the nominal exchange rate (i.e., the degree to which real exchange rates react to real asymmetric shocks). Such mechanisms might include, *inter alia*, factor mobility, fiscal policy, and the flexibility and shock-absorbing capacity of the financial sector.

- The degree to which the real exchange rate between the NMS and the eurozone is exposed to real asymmetric shocks. The degree of this symmetry would in turn depend on the similarities in price levels and GDP per capita, labour mobility, the synchronisation of business cycles, structural similarities, convergence of the interest rate differential between that NMS and the eurozone, the degree of trade openness and trade diversification of that NMS, the degree of stability in terms of trade, and financial market integration.

- The degree to which monetary policies in the NMS and the eurozone react symmetrically to symmetric shocks.

The lower the degree of real exchange rate volatility, the greater the extent of adjustment mechanisms other than the nominal exchange rate, and/or the lower the exposure of the NMS to asymmetric shocks, and/or the greater is the degree of symmetric monetary policy responses between the respective NMSs and the eurozone in response to symmetric shocks.

The existence of flexible adjustment mechanisms other than the nominal exchange rate, in the onset of unexpected real shocks, allows smooth tuning of macroeconomic imbalances, limiting the need for an exchange rate's adjustments. Given that symmetric shocks do not require adjustments in relative prices, they do not distort equilibrium. Consequently, *a less volatile real exchange rate indicates less scope for monetary and exchange rate independence*. These economic conditions, which guarantee a more stable real exchange rate, are also traditional arguments behind the successful creation of optimal currency areas (Mundell (1961), McKinnon (1963), Kenen (1969))[9].

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[9] The traditional arguments however have not gone unchallenged. Based on Mundell (1973), it has been argued that if members of a currency zone are financially integrated, then a high degree of

An additional advantage of the proposed definition of real convergence is that the real exchange rate volatility criterion does not depend on the exchange rate regime in place, nor on the fact that a system actually chosen is optimal for the country. It only relies on the assumption that *national price stability is desirable*, and that therefore the flexibility of the nominal exchange rate may be justified to avoid changes in the real exchange rate that entail inflation or deflation above or below the eurozone average.

However, without empirically verifying the shock-absorbing role of a nominal exchange rate it is not possible to assess to what extent giving up monetary and exchange rate independence actually constitutes a cost of euro adoption, and to what extent nominal flexibility facilitates convergence. Even if the analysis showed that a *high* degree of real exchange rate volatility is due to *real* shocks, the only inference one is able to convincingly draw - based on the proposed definition – is that it is not yet advisable to join ERMII or the eurozone (or both)[10]. Given the nature of the shock and the catching-up process in the NMSs, in many ways such a conclusion could be sufficient (i.e., it may be that the only appropriate way to move these countries to higher income levels is exactly via higher inflation, implying that these countries should not rush to give up their own currencies). Nevertheless, this conclusion could be further reinforced were one able to empirically confirm the nominal exchange rate's theoretical ability to induce rapid adjustments in the onset of idiosyncratic real shocks. Where this is the case, it would be possible to argue that the nominal exchange rate *is* an important channel for the real exchange rate changes, and thus plays a positive role during the convergence process (i.e., stabilises real shocks in the absence of other adjustment mechanisms and sluggish prices). Losing this instrument represents the cost of the monetary integration and

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symmetry of the shocks among them, although desirable, is no longer a prerequisite. This is because, in a currency area, asymmetric shocks can be smoothed through risk sharing – i.e. through portfolio diversification and pooling of foreign exchange reserves (see Błaszkiewicz-Schwartzman and Woźniak (2005) for an overview of this literature). However, the risk-sharing argument does not change the fact that, in the presence of nominal rigidities, fewer asymmetric shocks call for a smaller need to adjust, and that giving up monetary and exchange rate independence represents a cost of monetary unification. This remains the basis of the approach set out in this paper.

[10] Eichengreen (1991) argues that real exchange rate variance analysis is not able to distinguish between the size of a shock and the ability to cope with it. Even if his argument were true, here it is argued that it does not matter if the volatility is high due to the degree of asymmetry or because the absorbing potential of other adjustment mechanisms is low. The outcome is the same: it is costly to join the common currency area.

can have negative implications for countries' economic performance[11]. Of course, if this role is not confirmed, given high real asymmetries, recommendations on the timing of ERMII/ euro area accession would not change. Unless greater real convergence is achieved it may be too costly to share a common monetary policy. Still, it would be also obvious that since shocks cannot be addressed by monetary policy, the only way to achieve real convergence is via implementation of structural reforms. Moreover, if the nominal exchange rate did *not* play a shock-stabilising role, the scale of real shock asymmetry would indicate the degree of flexibility of other adjustment mechanisms (i.e. labour mobility or real wages)[12].

The analysis of real convergence developed in this chapter builds on two strands of empirical literature with roots in the early theory of optimal currency areas (OCAs). The first of these focuses on the degree of real asymmetry between countries or regions wishing to constitute currency areas (Vaubel (1976, 1978), von Hagen and Neumann (1994), Gros and Hobza (2003), Błaszkiewicz-Schwartzman and Woźniak (2005)). The second strand of empirical literature attempts to test the main assumption of the OCA theory, and detect whether exchange rate flexibility is a significant stabilizer of real asymmetric shocks (Bayoumi and Eichengreen (1993), Clarida and Gali (1994), Canzoneri et al., (1996) in the context of developed countries, and Dibooglu and Kutan (2001) and Borghijs and Kuijs (2004) in the context of the NMSs). All these papers utilise standard assumptions of open macroeconomy sticky-price models in the spirit of Mundell-Fleming-Dornbusch, to

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[11] Whether or not exchange rates serve as effective shock stabilisers depends to a large extent on the price strategies governing firms' decisions (as stressed by New Open Economy Macro Models). For example, under conditions of local-currency-pricing, nominal currency changes would not change either real or nominal prices in the short run. However, in the context of the NMSs this is unlikely to be the case. Were it the case, observed real exchange rate volatility would have to be induced by market incompleteness and exporters' ability to discriminate against different markets, requiring that relative prices stay constant. Yet in the NMSs, inflation rates fell dramatically during the 1990s. (See also Engel (2002), who shows that if importer-distributors face pass-through to import-prices, then some flexibility may be still desirable. Similarly, Obstfeld (2002) provides empirical evidence that there is still an important role for exchange rate flexibility to play in changing relative prices). Therefore, it is probably fair to assume that nominal exchange rates are not totally 'disconnected' from the real economy in the NMSs and - at least to a certain degree - are able to provide equilibrating real exchange rate adjustments.

[12] Buiter (2000) emphasizes that the decision to join a monetary union, is a monetary issue. If prices of goods are flexible, relative-price behaviour is usually independent of the monetary regime. The choice of monetary regime only matters for short-run changes – the period during which nominal prices are adjusting. In this paper it is however argued that in the context of catching-up economies this decision does depend on the degree of real convergence, as the only way to reach higher income levels is via higher than the eurozone average growth rates, and thus inflation.

classify shocks in different SVAR systems. In common with this first strand of literature, this chapter focuses on real exchange rate volatility. In common with the second strand of literature, this chapter attempts to separate shocks governing movements of real and nominal exchange rates into their nominal and real components, and to detect the responses of nominal exchange rates to different types of disturbances.

The chapter uses a two-step univariate / bivariate econometric methodology. In step one, the univariate variance approach measures the degree (magnitude) of unexpected real exchange rate variance, and thus the degree of real convergence[13]. In step two, the bivariate approach utilizes a BQ-SVAR analysis to identify nominal and real factors driving real and nominal exchange rate movements. The BQ-SVAR methodology also allows for an analysis of the potentially stabilising role of nominal exchange rates and thus an assessment of the cost of euro adoption. The two-stage strategy is necessary for two reasons. First, it is essential for the accurate measurement of real convergence. This is because, as mentioned, the univariate variance approach cannot convincingly distinguish between nominal and real shocks in real exchange rate movements, and therefore by itself is not well designed to accurately assess the degree of real convergence. Therefore, the BQ-SVAR methodology is used to separate and measure the magnitudes of real and nominal components in real exchange rate movements. Second, the BQ-SVAR approach provides an indication of the shock-stabilising role that the nominal exchange rate plays in any NMS – i.e. the methodology establishes if the nominal exchange rate indeed responds to asymmetric real shocks, and moves together and in the same direction as the real exchange rate in order to ensure the necessary change in relative prices. Thus, the BQ-SVAR analysis makes it possible to assess to what extent giving up monetary and exchange rate independence actually constitutes a cost of the euro adoption, and to what extent nominal flexibility facilitates real convergence.

While the BQ-SVAR analysis conducted in this chapter provides results useful to the policy questions raised by the prospect of the euro adoption, it is not without

[13] Since there are various ways in which the degree of RER volatility can be measured, the final choice of the econometric methodology implemented in this paper is discussed in section 1.4.1.

limitations, noted below. The broad decomposition of shocks into real and nominal components is both a strength and weakness. On one hand, the methodology does indicate whether or not nominal exchange rates move in the same direction as real exchange rates at the onset of a real shock, pointing to the stabilising role of the nominal exchange rate. On the other hand, it is not able to assess fully the destabilising role of the nominal exchange rate at the onset of the nominal shock. Even if the ex-post data revealed that variations in the nominal exchange rate were caused by a different type of shock to variations in the real rate, this could not be conclusively interpreted as an indication of the ineffectiveness of the nominal exchange rate to stabilise nominal shocks. An equivalently valid explanation could be that a nominal exchange rate fully cushioned the impact of a nominal shock on a relative price. This argument could be even stronger, given that nominal shocks represent a whole range of temporary shocks, such as supply, demand or monetary and financial shocks[14]. The only inference one would be able to make from such a result, would be that neither monetary policy nor fiscal policy can change competitiveness of a given country (and vice-versa, provided nominal shocks turned out to be important in real and nominal exchange rate movements). However, to the extent that the primary interest of this chapter is to assess the importance of permanent movements in the real exchange rate, and the potential role of flexible regimes in stabilising permanent shocks (i.e., demand and supply shocks related to the convergence process) this decomposition is sufficient.

Although some of the existing empirical literature with roots in the early theory of OCA does focus on the NMSs of the EU, their goals and analytical tools are different to the one set out in this study. For example, Gros and Hobza (2003) measure an observed rather than unexpected real and nominal exchange rate variability as an alternative OCA criterion for the NMSs (or rather the candidate EU countries). Based on their analysis they come to the conclusion that the still remaining variability of real exchange rates in Central Europe might be mostly due

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[14] The same arguments apply to the 3-equation VAR system, and therefore the estimation of such a system would also fail to fully resolve the question of whether flexible exchange rates are destabilizing or not. It is true that a three-variable SVAR model distinguishes between demand and supply shocks (which the bivariate system cannot), but again its identification specification is not able to unambiguously separate between impact of the temporary supply and monetary/financial shocks on the short-run behaviour of the nominal exchange rate.

to the fact that nominal exchange rates are still a source of shocks. However, they do not formally separate the shocks that affect the real and nominal exchange rates. Their conclusion is based on the fact that nominal exchange rates are more volatile than real rates. The problem with this kind of analysis is that it is not possible to detect whether the real and nominal exchange rates are governed by the same or different types of shocks. It also says nothing about the stabilizing role of nominal exchange rates.

Although, Dibooglu and Kutan (2001) also utilize a two-dimensional BQ-SVAR methodology (on a differenced real exchange rate and prices) in investigating the sources of real exchange rate movements in Hungary and Poland, the aim of their paper differs from the one pursued here[15]. The authors examine the proposition that different fiscal and monetary policies in transition countries should lead to the predominance of real shocks in some countries, but nominal shocks in others and covers the period between 1990 and 1999. Their results suggest that during that time the Polish real exchange rate was mainly driven by nominal shocks (in the short-run) whereas the Hungarian real exchange rate was driven by real shocks. However, the span of their sample includes a period of little nominal exchange rate flexibility and therefore cannot address the issues discussed in this chapter. Also, they do not measure the size of real exchange rate volatility and therefore, based on their paper, very little insight about the process of real convergence can be gleaned.

Finally, in a paper by Borghijs and Kuijs (2004), an investigation is made of whether for five NMSs - the Czech Republic, Hungary, Poland, the Slovak Republic, and Slovenia - nominal exchange rate flexibility is a useful absorber of real shocks or an unhelpful propagator of monetary and financial shocks. The authors work within a three-equation model in the spirit of Clarida and Gali (1994), and answer similar questions to Canzoneri et al. (1996), but their SVAR model includes a nominal exchange rate instead of prices, since they argue that the loss of nominal exchange rate flexibility is the key cost of euro area participation. However, as pointed out above, the role of the nominal exchange rate as a shock absorber is only relevant if

[15] The papers which identify sources of nominal and real exchange rates fluctuations within the bivariate BQ-SVAR models in developed countries include, among others, the works of Lastrapes (1992) and Enders and Lee (1997).

there are large real asymmetries between the economies wishing to form a common currency zone – the issue addressed in this chapter. This is because even if a nominal exchange rate were not addressing macroeconomic imbalances and its movements were only a reflection of money and financial market shocks, one could not say that there is no cost from losing monetary and exchange rate independence.

Application of the two-step methodology proposed here, and as described in more detail in sections below, suggests that real asymmetric shocks (i.e., the degree of real exchange rate volatility scaled down for the presence of nominal shocks) in the NMSs (with the exception of Slovenia and Estonia) outsize those experienced by OMSs at the time of their euro adoption process. This finding suggests that the NMSs are still converging in real terms on the basis of the proposed indicator. Additionally, it is found that in the NMSs the nominal exchange rate *does* play a stabilising role (with the exception of Slovenia), and that nominal shocks do not, on average, move real exchange rates. Given that the benefits of monetary union are not immediately obvious at present, some caution should be exercised in timing the ERMII accession and euro adoption.

1.3 DATA ANALYSIS

The rationale for the choice of countries used in the sample, as well as the sample time span for both the univariate and bivariate analysis, are set out below. Since the data employed in the study should be stationary, the recent evolution is discussed of the real and nominal exchange rate against the euro as well as price movements in the selected countries, as a pre-step towards detecting integration properties of the data. Finally, formal unit root tests are conducted.

1.3.1 Sample Choice and Size

The NMSs analysed in this study include the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic and Slovenia. The sample for inclusion in the two step univariate / bivariate methodology used in this chapter gives rise to the following issues:

- First, while all NMSs can be included in the univariate sample (i.e., because of a real exchange rate flexibility), bivariate SVAR analysis (with real and nominal exchange rates) can only be applied to countries with relatively flexible nominal exchange rates. As a result, not all the countries included in the univariate analysis were included in the bivariate analysis.

- Second, countries included in the SVAR analysis must have *de facto* variable exchange rates. In some cases, *de facto* exchange rates differ from officially announced exchange rate regimes. In order to distinguish between different exchange rate regimes, officially announced exchange rate arrangements (as published by the IMF) were cross-checked with the classification developed by Reinhart and Rogoff (2002)[16]. According to both classification schemes, the exchange rates of Czech Republic, Hungary, Poland, the Slovak Republic, and Slovenia may be regarded as relatively flexible exchange rates. The exchange rates of Estonia, Latvia, and Lithuania are regarded as fixed, and could not be included in the bivariate SVAR analysis[17]. Box 1.1 reviews the evolution of nominal exchange rate regimes in the five NMSs which may be regarded as having flexible exchange rates.

- Third, meaningful structural analysis requires sufficiently long data span. Unfortunately, for countries under consideration, reliable data only exists from the beginning of the 1990s. As a result, for the univariate analysis the estimation period spans 1993M1 to 2007M11. Prior to this period, the data is contaminated by structural changes related to the transition process. The data span used for the bivariate analysis is based on the *de facto* flexible exchange rate regime in place, as described in Box 1.1.

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[16] Because Reinhart and Rogoff's study goes to December 2001, exchange rate regimes between 2001M12 and 2007M11 were classified in accordance with the IMF code.
[17] From now on, whenever the reference is made to the *de facto* exchange rate regime, it refers to Reinhart and Rogoff's classification.

Box 1.1 Evolution of Exchange Rate Regimes in the Czech Republic, Hungary, Poland, the Slovak Republic, and Slovenia (Choice of Sample Size).

In the *Czech Republic,* exchange rate flexibility was limited before 1996. Initially the official exchange rate was tied to a currency basket and then to the ECU. *De facto*, however, the country had a crawling band system around the DM (with a band width of ±2%). More flexibility was introduced in May 1997. The Czech koruna was officially classified as a pre-announced crawling band around the DM with a band width of ± 7.5% (*de facto* the band width was ±5%). Because, between 1993M1 and 1996M3, the official regime was less flexible than indicated by the *de facto* regime, the final sample for the Czech Republic spans from 1996M3 to 2007M11.

In *Hungary*, until December 1998, the exchange rate regime was a *de facto* crawling band around the DM, with a band width of ±5%, until May 1994, and ±2% between May 1994 and January 1999. From January 1999 to December 2001, the exchange rate was *de facto* classified as a pre-announced crawling band around the euro. Officially, more flexibility was introduced in May 2001. The crawling band was widened from ±2.25% to ±15%. While more official flexibility was announced in 2001, it is not possible to conduct analysis on so few data points. Given this, and the fact that there was already some flexibility before 2001, the estimation period used for Hungary covers the years 1993M1-2007M11.

The sample size for *Poland* starts in June 1995 since before that a *de facto* exchange rate regime was either classified as freely falling (i.e., period of hyperinflation) or dual market. From mid-May 1995 up to February 1998, the *de facto* regime was classified as a crawling band around the euro (ECU) with a band width of ±5%; there was a pre-announced crawling band around the DM and the US dollar of ±7%. Between February 1998 and April 2000, the band width was systematically widened (up to ±15%). In April 2000, a float was introduced (i.e., a *de facto* managed float). The regime has not changed since then. The final sample size spans 1995M6 to 2007M11.

In *Slovakia* exchange rate flexibility was introduced gradually. Between 1993M1 and 1996M7, the currency was *de facto* governed by a crawling band regime around the DM with a band width of ±2%. The band width did not change up to September 1997, but between August 1996 and September 1997 the pre-announced crawling band was progressively widened to ±7%. As of September 1997, *de facto* the band was widened to ±5% and a pre-announced crawling band of ±7% was maintained. Even though the managed float system was introduced in October 1998, according to Reinhart and Rogoff, between October 1998 and December 2001, all the observations remained within a ±5% band of DM/euro. Taking into account policy changes in the exchange rate regime, the estimation period starts in 1996M8 and ends in 2007M11.

Between the years 1993 and 2004, the nominal exchange rate in *Slovenia* was governed by a de facto crawling band around either the DM, or euro with a band width of ±2% (euro/ECU replaced DM in October 1996). From June 2004 Slovenia has been participating in the ERMII system in which the exchange rate is allowed to fluctuate by ±15%. Unfortunately, the period of greater de jure flexibility is not long enough to perform the estimation. Therefore, estimation based on data spanning 1993M4 to 2006M12 has been used (before April 1993 a de facto regime was classified as freely falling; Slovenia adopted the euro on January 1 2007). The final results, however, are presented for the period 1996M1 to 2006M12 (this relates to issues of heteroskedasticity, and will be discussed in further depth below).

Source: Compiled by the author based on Reinhart and Rogoff (2002) and the IMF classification.

The sample of current euro area countries chosen for comparison with the NMSs includes Italy, Greece, Portugal and Spain (the so-called Club Med countries) as well as France and Germany. The Club Med countries are regarded as belonging to the periphery of the EU, while France and Germany are chosen to represent the core of the EU. The span of data for chosen eurozone countries runs from January 1993 to December 1998 (nominal (and real) exchange rates for the OMSs are calculated against the ECU, which was replaced by the euro at a rate of 1:1 on 1 January 1999). This choice reflects the following two factors: First, 1993 marks the end of the European Monetary System, which allowed nominal exchange rates to fluctuate within a band of +/-15 percent. This ensures minimum policy coordination between countries and is important for comparative purposes. Data after December 1998 is not considered, as for the purposes of this study, the performance of countries after their entry into the eurozone in January 1999 is not of interest.

Unfortunately, the only country within this selected group with a *de facto* floating exchange rate regime was Germany (according to the Reinhart and Rogoff's classification). Nevertheless, because between 1993 and 1998 the Club Med countries as well as France adopted some kind of peg or crawling band regime against the DM, at the same time fluctuating freely around the ECU, they are all included in the SVAR modelling.

1.3.2 Data Source and Transformation

For all NMSs, monthly data on period average nominal exchange rates, against the euro, up to November 2007 were sourced from Eurostat. Eurostat also provided data for the former eurozone national currencies vs. euro (ecu) considered in the sample as well as the euro area consumer price index (HICP). Consumer price indices (CPIs) for the New and Old Member States were taken from the IMF IFS[18]. All series were transformed into logarithms, and scaled with the base period set to 100 in 2005 for the NMSs, and to 1995 for the OMSs. The individual real exchange rate indices were calculated as nominal NMS (OMS)/euro rates, deflated by the relevant consumer price indices (i.e. CPI for NMSs and OMSs, and HICP for the eurozone)[19].

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[18] HICP indices for NMSs are not available over the time period estimated in this study.
[19] An increase in the index indicates currency depreciation relatively to the euro.

1.3.3 Graphical Presentation

Figure A.1 in Annex A.1 presents the developments of real and nominal exchange rates (indices, 2005=100 transformed into natural logarithms) as well as price ratios (defined as P^{EMU}/P, indices, 2005=100 transformed into natural logarithms) between 1993M1 and 2007M11, for the NMSs included in the univariate and/or bivariate variance analysis[20]. It shows that in countries with relatively flexible nominal exchange rates, real and nominal exchange rates tend to move together (and appreciate), as indicated by the coinciding turning points[21]. This outcome is confirmed by the simple correlation between real and nominal exchange rates in these countries. This coefficient is approximately 0.9 for the Czech Republic, Hungary, Latvia, Poland and Slovakia and equal to approximately 0.8 for Lithuania, and Slovenia. The lowest comovements between real and nominal exchange rates are observed in Estonia, where the correlation coefficient is 0.3 (see Table A.1.1 in Annex A.1 for details). Despite a high correlation, over time, nominal and real exchange rates diverge or move in different directions in the case of Hungary and Slovenia[22]. The differences in the short and long-term dynamics of real and nominal exchange rate point to the presence of two different types of shocks affecting these countries: one temporary and one permanent in nature. This is consistent with the predictions of the broad class of structural open macro models (i.e., Dornbusch's (1976) 'overshooting' model or Stockman's (1987) 'equilibrium' model). Given that the divergence of the rates occurs quickly, there exists a strong pre-assumption that permanent shocks dominate real exchange rate movement.

1.3.4 Integration Properties

This section formally tests the unit root hypothesis for the data series used in this study. In the case of the univariate analysis, nonstationarity of data in levels would imply that real exchange rate movements cannot be characterised by their average

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[20] The results of analysis conducted on the OMSs treated in this paper are not discussed in detail, as they only serve a point of comparison.
[21] These observations are not unique. Enders and Lee (1997), for instance, have noted similar trends in Canada and Japan.
[22] Given the objective of monetary authorities to keep the real exchange rate constant in Slovenia, and to limit initial flexibility in Hungary until 2001, this is not surprising.

values. In such cases it would be inappropriate to use standard measures of volatility, such as variance/ standard deviation of the series. Stationary data is also required for the Blanchard and Quah decomposition of the SVAR model. Moreover, the variables in a VAR should not be cointegrated if the data in levels is non-stationary[23]. To test cointegration between the pairs of nominal and real exchange rates entering the VAR, it is enough to check the integration properties of price ratios in levels (i.e., the price ratio between the eurozone and country of interest inflation) (see Enders and Lee (1997)). Only when all the variables are I(1) and no cointegrating relationship exists, is it appropriate to estimate the VAR in first differences. The results of the formal unit root analysis discussed below should however be treated with great caution as the time span on which the tests are conducted is very short.

Following Maddala and Kim's (1999) argument that the Dickey-Fuller, augmented DF, and Philips-Perron unit root tests do not have enough power to meaningfully reject the null hypothesis, these tests are not used. Instead, in this study the DF-GLS test of Elliot-Rothenberg and Stock (1996) as well as the class of MZt and MZa tests of Ng and Perron (2001) are applied. As suggested by Ng and Perron (2001) (based on Monte Carlo simulations), in order to maximize the power, all tests are based on GLS detrending; likewise, in order to minimise the size distortion under the null (and not over-parameterise under the alternative), the choice of the lag length is selected on the basis of the Modified Akaike Information Criteria (MAIC). The maximum number of lags is set in accordance with the rule suggested by Schwert (1989). Given that DF-GLS and MZ-GLS tests may not be appropriate for variables with an apparent structural break (see Perron (1989), Christiano (1992), Zivot and Andrews (1992)), the unit root test of Perron (1997) which allows a parsimonious single structural break is also carried out. The structural break date is treated as unknown and chosen so as to minimize the t-statistic on the α coefficient (i.e., model 3 in Perron (1997, p. 358)). The number of lags is determined by the 'general-to-specific' procedure with the maximum number of lags specified as in the previous tests.

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[23] If the variables were cointegrated, then, Error Correction Model and not the first differenced VAR system should be estimated.

The performed DF-GLS and MZ tests (the unit root is the null hypothesis in both tests) indicate non-stationarity of the investigated data (i.e., the data is I(1) - see Annex A.1, Table A.1.2) for all the series to be used in the univariate and bivariate modelling, but for the real exchange rate for Slovenia. The result for Slovenia, however, was not confirmed by the unit root test with a break (i.e. the unit root null hypothesis could not be rejected (see Annex A.1, Table A.1.3) where the test statistic row is called 'ADF'). However, based on the unit root test with a break, in the case of Hungary, France and Slovenia, there is some evidence of the stationarity of the nominal exchange rate (Hungary and Slovenia) and price ratio (France). Therefore, as a check, the Kwiatkowski, Phillips, Schmidt and Shin's (KPSS) test was done. This test sets a stationarity hypothesis as the null and was suggested by Maddala and Kim (1999) as confirmatory analysis[24]. In this case, a stationarity hypothesis for the Slovenian real and Hungarian nominal exchange rates as well as the price ratio series for France was rejected at the 1%, 5% and 10% level, respectively.

Based on the results from the unit root test, the series of real and nominal exchange rate used in this study enter univariate and bivariate estimations in first differences. Additionally, all the countries selected in Section 1.3.1 above, are included in the SVAR modelling, since: (i) all the exchange rate series of countries previously proposed for the structural VAR analysis are non-stationary in levels (with some uncertainty as far as the real and nominal exchange rate in Slovenia and Hungary are concerned); and (ii) the integration properties of the ratio of prices in levels do not suggest cointegration between respective pairs of nominal and real exchange rates in those countries (with some uncertainty in the French case). Once again, given the short span on the data, the performed tests are rather indicative than conclusive[25].

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[24] Confirmatory analysis is understood as a situation in which one simultaneously rejects (cannot reject) a unit root hypothesis with DF-GLS and MZ type of tests and fails to reject (rejects) stationarity hypothesis with a KPSS test. Were it the case, there is a stronger and mutually reinforcing evidence that the series being tested is (non) stationary.

[25] Dibooglu and Kutan (2001) argue that assuming non-stationary real exchange rates in transition economies is reasonable as purchasing power parity, implying stationary real exchange rates, holds under very restrictive conditions, which are extremely unlikely to be met in the case of the transition economies. Moreover, equilibrium real exchange rates in these countries should exhibit an upward trend over time due to the catching up process and as productivity and real wages increase over time. Because such shocks are generally stochastic in nature, there is a strong presumption that real exchange rates should have a permanent component during the time-span covered by their study. The same arguments should hold for the NMSs in the period of 1993-2007.

1.4 ECONOMETRIC METHODOLOGY

The univariate and bivariate components of the econometric methodology employed in the study are explained in further detail below.

1.4.1 Univariate Variance Analysis: Technical Aspects

To provide an estimate of the degree of real convergence in terms of real exchange rate volatility (measured in terms of standard deviation) between the selected NMSs and the eurozone, as well as to assess whether the NMSs are converging over time in real terms, in step one, a univariate variance analysis of real exchange rates in countries of interest is performed. To assess the convergence process in the NMSs (i.e., to decide when the RER variance should be considered large and when small), the variance analysis also covers the selected OMSs prior to their eurozone membership. There are various ways that the univariate variance analysis can be conducted. In this study, what are of interest are fluctuations of real exchange rates which cannot be explained by their past movements, i.e. *unexpected* real exchange rates' variances (standard deviations). Therefore, two types of econometric models of real exchange rate series for the New and Old Member States are estimated: AR(p) and AR(p)-GARCH(p,q). The general steps taken in the analysis are described below.

First, AR(p) models are estimated on two selected groups of countries across the full sample for each country, ARCH tests are conducted. The ARCH tests are necessary to determine the most appropriate way of measuring convergence. For example, if real exchange rates in selected countries follow an ARCH/ GARCH process, real convergence in the NMSs and OMSs should be measured through conditional variances. If not, then unconditional variances should be used. Second, to see whether changes in the RER variance are statistically significant over time or not, an estimation of AR(p) models on different sub-samples is conducted. Various statistical tests are then performed to assess variance equality *between* the selected sub-samples. Third, motivated by the results of the AR(p) modelling, AR(p)-GARCH(p,q) models for the NMSs and OMSs (on the whole sample as well as different sub-samples) are estimated, and the magnitudes of time varying conditional variances (standard deviations) for real exchange rates are obtained. In order to gain a better picture about the convergence process over time, in addition to the magnitudes for the whole sample, the conditional standard deviations (CSDs) for different sub-samples are also calculated. Finally, the plots of time varying conditional variances for real exchange rates are also analysed. Both the magnitudes and the plots should help to see whether the analysed countries are indeed converging over time in real terms. Moreover, the performance of the evaluation over the whole estimated sample avoids the need to make a somewhat arbitrary split of the sample into sub-samples (which split is required in statistical tests of the residuals obtained from the estimated AR(p) models).

As indicated in the introduction to this chapter, the univariate variance approach is only well designed to accurately assess the degree of real convergence if – among other things – it can precisely measure the degree of real shock asymmetry (i.e. the degree of real exchange rate variability due to real shocks), and thus the degree of real convergence. To this end, nominal shocks should be eliminated from real exchange rate movements. This is not an easy task and constitutes one of the main drawbacks of the proposed univariate variance analysis. Therefore, in the final step of the univariate variance analysis, an attempt is made to tackle this problem. Von Hagen and Neumann (1994) make a strong assumption that high-frequency (monthly) real exchange rate changes mostly reflect nominal shocks, and low-frequency (quarterly) real exchange rate changes are principally due to real shocks[26]. This approach is also followed here. The AR(p)-GARCH (p,q) models are estimated on quarterly data, and plots of the time varying conditional variances are analysed. Unfortunately, because the low-frequency analysis necessarily means using fewer data points in the already small sample, a quarterly univariate variance analysis for the New and Old Member States is only performed on the whole sample, i.e. estimations for the respective sub-samples for the OMSs are not done.

[26] It is however unclear/ debatable whether quarterly real exchange rate movements are freed from nominal shocks (i.e., nominal shocks could be more persistent).

In what follows, the technical details of the analysis detailed above are described. Given the unit root processes in the data (see Section 1.3.4), the AR(p) analysis on monthly data begins with a calculation of the unexpected RER component for each country in question (indexed by *i*) by regressing RER changes on their own lags by OLS, as follows[27]:

$$\Delta rer_{i,t} = b_0 + b_1 \Delta rer_{i,t-1} + b_2 \Delta rer_{i,t-2} + ... + b_{12} \Delta rer_{i,t-12} + u_{i,t} \quad (1.1)$$

where $\Delta rer_{i,t}$ is the change in the real exchange rate.

Residuals obtained from these regressions represent unexpected real exchange rate shocks. Next, the unconditional standard deviations of these shocks are calculated, which provide a measure of real convergence[28]. This exercise is done for each country over the whole analysed sample as well as different sub-samples. The whole sample for the NMSs runs from 1993M1 to 2007M11, for the OMSs from 1993M1 to 1998M12 (see Section 1.3.1). There are three sub-samples for the NMSs, i.e. 1993-1995, 1996-1998, 1999-2006/7, which roughly represent the periods of the movement of nominal exchange rate regimes toward greater flexibility (see Egert and Kierzenkowski (2003)). For the selected OMSs, two sub-samples are selected: one prior to the participation of these countries in the ERMII (1993-1995), the other prior to euro adoption (1996-1998). Subsequently, various statistical tests are performed. To determine whether unconditional or conditional standard deviations should be used to test real convergence, ARCH tests on the whole sample are done. To test for variance equality between different subsamples, White's tests for heteroskedasticity are carried out following Von Hagen and Neumann (1994). However, ARCH tests are also performed as financial market data often follow an ARCH/GARCH process.

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[27] The final number of lags in individual AR(p) and AR(p)-GARCH(p,q) equations was determined by the 'general-to-specific' approach.

[28] As discussed in Part 1.1, this approach draws on Vaubel (1976, 1978) and is similar to that of von Hagen and Neumann (1994), Błaszkiewicz-Schwartzman and Woźniak (2005) and Gros and Hobza (2003). However, the estimation methods in these studies differ from the method utilized in this paper.

Having tested for ARCH residuals in the AR(p) models, AR(p)-GARCH(p,q) modelling is done for all the New and Old Members States included in the study. AR(p)-GARCH(p,q) models are estimated despite the fact that in three tested countries (Poland, Germany and Spain) the ARCH process could not be confirmed (see Annex A.1, Table A.1.4 and Table A.1.5). However, since the ARCH test is an asymptotic test and the estimated sample size is very small, in the end the conditional standard deviations as a final measure of real convergence are preferred[29]. Similar to the approach taken in the AR(p) analysis, AR(p)-GARCH(p,q) modelling begins with an estimation real exchange rate changes on their own lags, by the means of OLS (i.e. equation (1.1) is again estimated). Additionally, however, the conditional variance equation is specified and estimated. Its general representation is as follows:

$$\sigma_{i,t}^2 = \omega + \sum_{j=1}^{q} \beta_j^i \sigma_{i,t-j}^2 + \sum_{s=1}^{p} \alpha_s^i u_{i,t-s}^2 \qquad (1.2)$$

where ω is the constant term, $u_{i,t-s}^2$ is the news about volatility from the previous period measured as the lag of the squared residual from the equation (1.1) (the ARCH term), and $\sigma_{i,t-j}^2$ is the last period's forecast variance (the GARCH term).

From the above conditional variance equation, the magnitudes and the plots of the estimated time varying conditional standard deviations (CSDs) for real exchange rates are obtained, and the average magnitudes of CSDs for different sub-samples are calculated. The results of the univariate variance analysis are presented in Section 1.5.1.

1.4.2 Bivariate Variance Analysis: Technical Aspects

As mentioned in the Introduction and emphasised in Section 1.4.1, univariate variance analysis is not well designed to detect how much of the real exchange rate volatility in countries of interest can be due to nominal shocks. Unless these are

[29] Using conditional standard deviations for all countries also ensures comparability of the results.

eliminated, the proposed measure of real convergence may be biased. Although the low-frequency univariate variance analysis should help eliminate nominal disturbances from real exchange rate movements, its reliability is questionable, due to its limitations (see footnote 26) and data constraints. Therefore, in this study, in step two, the structural (long-run) VAR analysis with a Blanchard and Quah decomposition is conducted. This not only allows separation of real and nominal shocks causing real exchange rate fluctuations, but also helps to detect the shock-stabilizing role of nominal exchange rates. The technical aspects of this analysis are discussed below.

Given that the variables of interest, real and nominal exchange rates (rer_t and ner_t, respectively), have a single unit root (and are not cointegrated), the VAR model considered in the study can be written as follows:

(1.3) $$B\Delta y_t = \Gamma_0 + \Gamma(L)\Delta y_{t-1} + \varepsilon_t$$

where $\Delta y_t = (\Delta rer_t, \Delta ner_t)'$, B is a 2×2 invertible matrix, Γ_0 is a 2×1 matrix of constants, $\Gamma(L)$ is a 2×2 polynomial in the lag operator, and $\varepsilon_t = (\varepsilon_{1t}\ \ \varepsilon_{2t})'$ is a vector of white-noise structural disturbances, i.e., $\varepsilon_t \sim iid(0, D)$ with D being a variance-covariance matrix of structural disturbances. ε_{1t} is interpreted as a real shock with possible permanent effects on nominal and real exchange rates. ε_{2t} stands for a nominal shock with only short-run effects on a real exchange rate.

In terms of equilibrium real exchange rate modelling, this broad classification of shocks is consistent with predictions of the broad class of structural open macro models. For example, it fits the Dornbusch (1976) ‘overshooting’ model of a small open economy in which nominal shocks can have permanent effects on the nominal exchange rate, but only temporary effects on the real exchange rate (Lastrapes (1992), Enders and Lee (1997)). Also, given that real shocks can permanently affect real as well as nominal exchange rates, it is also consistent with the Stockman (1987) ‘equilibrium’ model. And finally, the long-run neutrality restriction on the real exchange rate following a nominal shock is also consistent with the implications of the NOEM and other DSGE models (Obstfeld and Rogoff (2000), Lane (2001)).

Given that there are more parameters than equations to be estimated, the inference starts from estimating the flowing reduced form VAR model by OLS[30]:

(1.4)
$$\Delta y_t = C_0 + C(L)\Delta y_{t-1} + e_t$$

where $C_0 = B^{-1}\Gamma_0$, $C(L) = B^{-1}\Gamma(L)$ and $e_t = B^{-1}\varepsilon_t$

It is further assumed that $e_t \sim iid(0,\Omega)$ where Ω is a variance-covariance matrix of the reduced form error term. This matrix can be expressed as:

(1.5)
$$\Omega = B^{-1}D(B^{-1})'$$

Now, in order to recover the structural disturbances, ε_t, from the reduced form VAR, B^{-1} must be identified. As Blanchard and Quah (1989) show, this can be done by imposing long-run (infinite-horizon) restrictions on the matrix of structural dynamics multipliers $\Theta(1)$ which can be obtained by estimating the moving average representation of Δy_t and then by re-writing it in terms of structural shock:

(1.6)
$$\Delta y_t = \mu + \Theta(L)\varepsilon_t$$

Because it was assumed that ε_{2t} has no long-run effect on a real exchange rate, $\Theta(1)$ can be obtained as a lower triangular. Since $\Theta(1)$ equals $(I - C(1))^{-1}B^{-1}$:

(1.7)
$$B^{-1} = [(I - C(1))\,\Theta(1)]$$

Using this expression, the reduced form long-run variance-covariance matrix can be expressed as:

(1.8)
$$[(I - C(1))^{-1}]\;\Omega\;[(I - C(1))']^{-1} = \Theta(1)D\,\Theta(1)'$$

The left hand side of this expression can by fully obtained by estimating the reduced form VAR by OLS. Normalising D to the identity matrix and given the imposed long-run restriction on $\Theta(1)$ enables $\Theta(1)$ to be fully identified through the system of

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[30] As discussed in Hamilton (1994) separate VAR equation can be estimated by OLS without losing efficiency since, with the normality assumption, OLS estimators are almost identical with the maximum likelihood (ML) estimators.

equations specified in eq. (1.8); when $\Theta(1)$ is identified, B^{-1} is also identified, and so are the *structural disturbances*, $\varepsilon_t = (\varepsilon_{1t}\ \varepsilon_{2t})'$:

$$(1.9) \qquad \lim_{s\to\infty}\begin{bmatrix} rer_{t+s} \\ ner_{t+s} \end{bmatrix} = \begin{bmatrix} \theta_{11}(1) & 0 \\ \theta_{21}(1) & \theta_{22}(1) \end{bmatrix}\begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

Given that $\Theta(1)$ is now fully identified, it is possible to test the additional identifying restriction $\theta_{22}(1) = 1$ (i.e., so far, in order to identify the system, it was assumed, in accordance with the broad class of open economy macro models, that the long-run effect of the nominal shocks on the real exchange rate is zero, i.e., $\theta_{12}(1) = 0$), which says that a nominal shock has a proportional effect on a nominal exchange rate (see Enders and Lee (1997)). Since a positive nominal shock should cause a currency to depreciate, even if the long-run impact of the shock is not proportional, the expected sign on the estimated coefficient $\theta_{22}(1)$ is positive.

1.5 ESTIMATION RESULTS

1.5.1 Univariate Variance Analysis.

Since ARCH tests indicate that conditional rather than unconditional standard deviations should be used to measure real convergence in the New and Old Member States (see Annex A.1, Table A.1.4, Table A.1.5 as well as a discussion in Section 1.4.1), in this section, the plots and magnitudes of the estimated time varying conditional variances of real exchange rate fluctuations (on a monthly and quarterly basis) are discussed in turn[31]. In addition, tests for variance equality between different sub-samples from AR(p) model runs are presented and analysed[32]. The results for the NMSs are contrasted with those obtained for the selected OMSs.

[31] In some instances, AR(p)-EGARCH(p,q) models were estimated instead of AR(p)-GARCH(p,q) models, as they provided a better fit.
[32] The unconditional standard deviations obtained from the AR(p) modelling are available from the author upon request. In most cases they however were of the same magnitude as conditional ones.

Figure A.2. 1 in Annex A.2 presents the plots of CSDs calculated for real exchange rates in the selected New and Old Member States over the period 1993M1-2007M11 and 1993M1-1998M12, respectively. As indicated in Section 1.4.1, the patterns of the variances recorded in the NMSs should help assess whether these countries are converging in real terms vis-à-vis the eurozone. When compared to the patterns observed for the OMSs, they should also provide an indication of whether the real convergence process in the NMSs has been similar to that observed in the OMSs prior to the formation of the eurozone.

Among the eight NMSs, the lowest and diminishing volatility is observed in Estonia and Slovenia. However, in Estonia, although still at the fairly low level, the conditional RER variance seems to pick up from 2004. In Latvia RER volatility dropped significantly between 1993 and 1995, and then after 2000 (although it again appears to be increasing since 2006). In the Czech Republic and Lithuania, visible progress in convergence is observed from around 2000 and 2002, respectively. The level of RER volatility in Slovakia was lower in the early 1990s, but increased again between 1998 and 2004. Since then, a slight moderation in the RER variance has been observed although without any explicit trends. In Hungary and Poland, over the whole estimated sample, conditional RER volatility demonstrates a fairly similar pattern, with no clear signs of convergence. Looking at the OMSs, the best performers in terms of the scale of the conditional variance of the RERs are Germany, France and Portugal. However, in the case of Portugal, despite a relatively low level of volatility, no progress in convergence can be observed[33]. Italy and Spain show signs of real convergence from around 1996 onwards. In Greece it is hard to detect any progress in convergence over the whole estimated period.

As postulated, the use of quarterly estimates attempt to eliminate nominal variability in real exchange rate movements and thus provide a more accurate measure of the real convergence process. The plots of the quarterly CSDs are presented in Annex A.2, Figure A.2.2. In Slovenia the quarterly CSD mostly confirms the patterns observed in the monthly data. In Estonia, although the quarterly CSD shows

[33] The result for Portugal comes from estimating EGARCH (0,1) model. GARCH (p,q) models were also tried, but the variance equation coefficients were found to be insignificant. Therefore, the EGARCH (0,1) model was selected.

a similar pattern to that of the monthly CSD, it exhibits an upward trend in volatility from 1997 (and not from 2004 as exhibited in the monthly data). In Latvia, quarterly data discloses less convergence than monthly data – after an initial drop in volatility, no further progress is visible. In the Czech Republic and Lithuania, like in Estonia, quarterly CSDs show similar patterns to that of monthly, but it seems that the magnitudes of quarterly variances exceed that of monthly. In Slovakia, although the quarterly volatility decreased after 2000, it is hard to see significant signs of convergence from then on. In Hungary and Poland quarterly data provides a clearer picture of the convergence process. The quarterly Hungarian CSD not only confirms a lack of progress in real convergence, but also reveals its divergence. In Poland, the quarterly data shows increases in the RER volatility up to 2002. However, since then – despite a high overall magnitude – a decreasing trend has been observed. Quarterly CSDs for the OMSs confirm the trends seen in the monthly data for most countries. The lowest (and decreasing) volatility is visible in Germany and France. In the case of Portugal, quarterly RER is more volatile than monthly RER, with again no visible convergence. This is also the case in Greece. In Italy and Spain, similar to monthly patterns, between 1995 and 1998 volatility was decreasing.

The precise magnitudes of the estimated time varying conditional standard deviations discussed above are summarised in Table 1.5.1. In addition to the magnitudes for the whole sample, the CSDs for different sub-samples are also calculated. As mentioned in Section 1.4.1, they represent averages of CSDs attained from the estimated GARCH/ EGARCH(p,q) models for the two whole samples (i.e. 1993M1-2007M11 for the NMSs and 1993M1-1998M12 for the OMSs).

Based on estimates for the whole sample, on a monthly basis, again, among the NMSs, Poland displays the highest real exchange rate volatility, Estonia and Slovenia the lowest[34]. For the full sample estimates, the average real exchange

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[34] The presence of the highest level of the real exchange rate volatility in the NMS sample in Poland could reflect the fact that Poland has the largest stock market in the region. It could also be related to a stronger presence than in other NMSs of nominal shocks, as nominal exchange rate flexibility is greater in Poland than in any of the other NMSs. As monthly RER volatility is most likely affected by these nominal disturbances, they could bias the results upwards. However, high RER volatility could also be due to the sluggish speed of structural reforms in Poland. It could also be due to both of these factors. The low volatility of the Slovenian RER is perhaps related to the fact that the policy objective

instability (i.e. standard deviation) in the selected NMSs is higher by approximately 1.3 times when compared with the Club Med countries (by 3.1 times when compared with the average for France and Germany, and by 1.7 times when compared with the average for the group of Club Med countries plus France and Germany (OMSs)). In terms of the results for the particular sub-samples, there are three countries for which monthly conditional standard deviations of real exchange rate shocks exhibit a consistent and decreasing trend. These are Estonia, Latvia and Slovenia. Hungary, Poland, and Slovakia managed to decrease the variance of real exchange rate shocks between the II and I sub-sample. Nevertheless, in the third sub-sample, real exchange rates became again more volatile in these countries. In the Czech Republic there is clear evidence of stabilizing policies between 1999 and 2006/07[35]. Similar to the Czech Republic, Lithuania managed to lower its RER volatility between the second and third sub-sample. Based on the estimates of AR(p) models on the two sub-samples (1993M1-1998M12 and 1996M1-2007M11), statistically significant changes seem to be taking place in the Czech Republic, Latvia, Poland and Slovenia in the first sub-sample and in all considered NMSs but Poland and Slovakia in the second sub-sample (see column 'Volatility Changes' in Table 1.5.1). When the average magnitudes of the Club Med real exchange rate shocks in the early 1990s, as well as in years preceding the creation of the eurozone are compared with the NMSs average for the years 1999 and 2006/07, the results show that, on average, the NMSs real exchange rate volatility is 1.7 times higher than the real exchange rate volatility of Club Med countries in years preceding eurozone membership (i.e., 1996 to 1998), and almost equal to the variance of Club Med countries in the early 1990s. It should be stressed however that for countries like Estonia and Slovenia, real exchange rate volatility in years 1999-2006/07 is smaller not only when compared with the Club Med countries, but also when France and Germany are added to the Club Med group (i.e. when compared with the 'OMSs' line in Table 1.5.1).

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of Slovenian authorities was to keep the real exchange rate constant. Slovenia also has the highest level of GDP per capita among all analysed NMSs, and thus it is not surprising that its level of convergence with the eurozone is greatest among the NMSs.

[35] i.e. the policies which were implemented after the Czech currency crisis in May 1997.

Table 1.5.1 Real Exchange Rate Volatility

VOLATILITY CHANGES		CSD I	CSD II	CSD III	GARCH M	GARCH Q
		93-95	**96-98**	**99-07**	**Full Sample**	
Czech Republic	No*/Yes*	0.84	1.64	1.22	1.23	1.45
Estonia	Yes/Yes*	1.23	0.56	0.40	0.57	0.54
Hungary	Yes/No*	1.28	1.22	1.30	1.28	1.12
Latvia	Yes*/Yes*	2.79	1.23	1.11	1.46	1.34
Lithuania	No/Yes*	1.71	1.80	1.09	1.33	1.43
Poland	Yes*/No	1.84	1.83	1.88	**1.86**	**1.88**
Slovakia	Yes/No	1.29	1.09	1.36	1.29	1.34
Slovenia	Yes*/Yes*	1.20	0.59	0.38	0.60	0.57
Average		**1.52**	**1.25**	**1.09**	**1.20**	**1.21**
Average (FRA and DEU)		***0.45***	***0.33***		***0.39***	***0.28***
Average (OMSs)		***0.89***	***0.53***		***0.73***	***0.64***
Average (ClubMed)		***1.11***	***0.63***		***0.89***	***0.82***

Note: Columns labelled 'CSD' report averages of conditional standard deviations (CSDs) calculated for selected sub-samples (on a monthly basis) from CSDs attained from estimating GARCH/EGARCH models for the whole sample (i.e. I-III). Columns labelled 'GARCH M' and 'GARCH Q' report CSDs from models estimated for the whole sample (on a monthly and quarterly basis, respectively). Quarterly CSDs were normalized to monthly CSDs. "Yes" indicates convergence, "No" indicates divergence, i.e., we observe a decrease/increase in the standard deviations of the real exchange rate between the two tested sub-samples (93-95 and 99-07); '*' marks differing variance of the error term of estimated AR(p) models of real exchange rate changes by OLS between the two sub-samples (based on p-values of conducted White Heteroskedasticity and/or ARCH tests and 10% significance levels reported in Annex A.1, Table A.1.4). Notice that the conclusions about convergence/ divergence based on the conditional and unconditional variances are the same.

Source: Author estimates based on IMF IFS and EUROSTAT data.

Turning to results obtained from the whole-sample quarterly estimates (normalized to monthly), in half of the NMSs (Czech Republic, Lithuania, Poland, and Slovakia) the magnitude of individual quarterly real exchange rate variances is higher than that of monthly[36]. In the model the assumption was made that unexpected quarterly real exchange rate volatility reflects real shocks that are free of short-run disturbances. The data shows that with the exception of Slovenia and Estonia, real exchange

[36] Recall that due to the short data span, the magnitudes of the quarterly CDSs for the selected sub-samples are not calculated. Therefore, the only way to discern quarterly changes in RER variances over time is to rely on the patters of the CDSs plots presented in Annex A.2, Figure A.3 and discussed above.

volatility calculated for the NMSs on a quarterly basis is on average 1.5 times higher than the volatility calculated for the Club Med countries. It is therefore clear that asymmetric real shocks are still an important source of real exchange rate volatility in these countries.

In summary, based on univariate analysis and the proposed definition of real convergence, it appears that only Slovenia and Estonia achieved a level of real convergence which is comparable with that of the selected OMSs in the onset of the euro adoption.

1.5.2 Bivariate Variance Analysis.

In what follows, the specifications of the VAR models used in this chapter are described and tested for adequacy. Next, the BQ-SVAR analysis described in Section 1.4.2 is implemented. This, together with the univariate analysis, establishes the basis for evaluating the differences between the degree of asymmetric real and nominal shocks in real exchange rates as well as verifies the shock absorbing role of nominal exchange rates in the analysing NMSs of the EU.

As a reminder, because of the unit root process, nominal and real exchange rates, enter VARs in first differences. The VAR lag order for each country is chosen based on the Akaike Information Criterion (AIC). The estimated lag length $\hat{p}$ is chosen for the value of p that minimises AIC(p), with the maximum number of lags of p_{max}=8 (and 6 for the OMSs). Although the AIC criterion tends to overestimate the number of selected lags, as shown by Kilian (2001), impulse response estimates tend to be highly sensitive to the underestimation of a lag order.

Model Specification and Checking.

Before one can move to the structural VAR analysis of shocks (i.e. to evaluating the contribution of nominal and real shocks to exchange rate movements), it is necessary to make sure that the errors from the estimated reduced form VAR models are normal, i.i.d and that they do not exhibit ARCH process. For the models to be correctly specified, the estimated residuals should be normally distributed, serially uncorrelated and have a constant variance. Moreover, since the structural VAR analysis needs to be conducted in constant economic structures, and since there have been frequent changes in the monetary and exchange rate regimes in the NMSs during the period under consideration (which could have disrupted a stable relationship between the variables), tests for structural changes are also performed.

Normality, Autocorrelation, Heteroskedasticity and ARCH.

In order to test whether the estimated VAR residuals exhibit any remaining autocorrelation, the Portmanteau and LM autocorrelation tests are executed. To test the normality assumption, the multivariate test of Doornik and Hansen (2008) is employed. Homoskedasticity is checked by performing general White's tests (joint test and tests for individual components with (i.e., test for heteroskedasticity and specification bias) and without cross-products (i.e., test for pure heteroskedasticity)). White's heteroskedasticity tests are primarily chosen because they neither require explicit formulation of the form of heteroscedasticity, nor do they require normality under the null hypothesis (i.e., no heteroskedasticity). The results of those tests are presented in Annex A.3, Table A.3.1)[37]. Additionally, and given the univariate analysis above, ARCH tests on individual residuals from VAR equations are performed.

Despite the fact that there seems to be no autocorrelation left in the residuals of the estimated VAR models, the results should be treated with caution because the misspecification autocorrelation tests are derived under the assumption of normally distributed errors, which is clearly violated in all cases but Poland (for the selected OMSs, three countries – Germany, Greece and Italy – do not pass normality tests). As indicated by White's tests, in the cases of Czech Republic, Slovakia, Slovenia, Spain, Italy and Portugal, the lack of normality could be due to heteroskedastic errors. In other countries, it could be because the distribution is skewed or leptokurtic, or simply because of the small sample size, which could be too small to confirm asymptotical normality. The results obtained from the conducted ARCH

[37] Since the results of Portmanteau tests did not differ from the results of LM tests, only the former are presented in Table A.3.1. The results of the LM tests can be obtained however from the author upon request.

tests indicate ARCH errors in the estimated RER equations for the Czech Republic, Portugal and Spain as well as for Slovakia and Portugal in the estimated NER equations (see Annex A.3, Table A.3.2). However, in all cases, correcting for detected structural breaks (see the next section), and / or using the WLS instead of the OLS estimator also corrected for ARCH in residuals (see Annex A.3, Table A.3.2). Ideally, a better strategy would be to estimate SVAR-MVGARCH models. However, given the small sample size, the proposed solution seems more adequate.

Structural Changes.

In order to tests for structural breaks, the techniques developed by Bai et al. (1998) and Hansen (2000) are employed. Both treat the break date as unknown. In light of various econometric studies, which document that testing for structural breaks with an *a priori* determined break date can be misleading, the choice of the methods seem adequate (Banerjee, Lumsdaine, and Stock (1992), Christiano (1992), Zivot and Andrews (1992)).

The advantage of using the Bai et al. (1998) method is that it tests for common breaks in multivariate time series (more precisely, it looks for the simultaneous break date in mean growth rates, treating autoregressive parameters as nuisance parameters). In doing so the procedure implements the "supremum" test of Andrews (1993) (i.e., Sup-Wald) and the related "average" and "exponential" tests of Andrews and Ploberger (1994) (i.e., SupF, ExpF, AveF tests)[38]. As shown by Bai et al. (1998), testing for simultaneous structural breaks in the VAR system improves estimation precision of a particular break date. Moreover, the authors construct confidence intervals for the break date that increase the estimation accuracy[39]. The difference between the Bai et al. (1998) test and that implemented in this study, is in the lag-

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[38] Andrews (1993) and Andrews and Ploberger (1994) provide critical values for SupF, ExpF, and AveF tests. Hansen (1997) calculates p-vales for those tests. His Gauss program is available at http//www.ssc.wisc.edu/~hansen/progs/progs.htm

[39] Bai et al. (1998) show that the width of the confidence interval decreases in an important way when series having a common break are treated as a group and estimation is carried using a quasi maximum likelihood (QML) procedure.

selection method. This is necessary in order to obtain models consistent with those employed in the SVAR analysis[40].

The disadvantage of the Bai et al. (1998) test is that it is based on the asymptotic distribution theory. Although, the asymptotic distribution is relatively easy to tabulate, it may be unreliable in finite samples. Additionally, because the Bai et al. (1998) test uses asymptotic critical values, calculated under the null of i.i.d. errors, it can be inadequate in persistent or/and heteroskedastic series. Given the results of the normality and heteroskedasticity tests performed on the estimated VARs residuals, the likelihood of obtaining misleading results may not be insignificant. For example, Hansen (2000) finds that asymptotic distributions of Andrews' (1993) test statistics depend on the presence of a unit root and/or structural change in the regressors (i.e., they are not robust to structural change in the marginal distribution of the regressors), and thus the stationarity assumption underlying those tests may result in inadequate inference. Also, Diebold and Chen (1996) provide evidence of size distortions (i.e., tendency to over-reject) of supremum tests for a structural change in dynamic models. This poses a problem in testing conditional relationships, since these tests cannot differentiate between structural change in conditional and marginal distributions. As such, they are not of much use to policymakers. For example, the marginal model can be thought of as an instrument that can be moved in order to achieve some goal (i.e., expressed by the conditional model). For policy purposes, of interest is the question whether the conditional model has invariant parameters, despite changes in the marginal model. In the context of this study, the question is whether the parameters of the estimated VAR equations are stable, despite changes in the exchange rate regimes, changes to the rate of growth of money, etc. To this end Hansen (2000) proposes the 'fixed regressor bootstrap' which allows for arbitrary structural change in the regressors, including the lagged dependent variable and heteroskedastic error process. He further shows that this bootstrap technique produces the correct asymptotic distribution and also leads to reasonable size properties in finite samples. Therefore, in this study, the results of structural break

[40] Bai et al.'s Gauss program was modified to select the break date on the basis of the minimum AIC value as opposed to BIC value preferred by the authors.

tests obtained by implementing the Bai et al. (1998) procedure are contrasted with those obtained by implementing Hansen's (2000) bootstrap technique[41].

Test Results

Based on the Bai et al. (1998) test, a break date in the mean at a common break date of real and nominal exchange rates is statistically significant for Slovakia (in 2000M11) and Spain (in 1994M11). For the rest of the countries, there is no evidence of shifts in the mean growth rates (Annex A.3, Table A.3.2). The results obtained from the test due to Hansen are different (Annex A.3, Table A.3.3). According to the p-values, there is evidence of coefficient instability in the Czech Republic, Hungary, and Slovenia in the NMSs group (in Poland only one tests appears to provide evidence for a possible break in the nominal exchange rate); and Portugal in the OMS group. However, in Hungary and Slovenia, once the tests are robust to the presence of heteroskedasticity, a potential structural break is confirmed only by the AveF test. The fact that estimated break dates cannot be confirmed by both tests is somewhat disturbing. Therefore, the CUSUM structural stability tests were also performed (for those countries for which the Hansen test corrected for the presence of heteroskedasticity indicate structural breaks). The results are presented in Annex A.3, Figure A.3.1. A plot of cumulative sum of residuals did confirm parameters' instability in the case of Czech Republic at the 5% level for both VAR equations. In Slovenia, a plot of cumulative sum and sum of squared residuals indicated parameter or variance instability in the nominal exchange rate equation. In the case of Hungary and Poland, neither CUSUM not CUSUM squared tests revealed the presence of a structural break. In Portugal, both tests strongly confirmed the presence of the structural break.

As documented by Diebold and Chen (1996), the Bai at al. (1998) test suffers from over-rejection, and since the CUSUM tests mostly confirmed the results obtained from Hansen's (2000) tests, the later two are treated as superior. To this end, the

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[41] Given that results of the unit root tests may not robust, and the potential lack of normality of the data, as well as the presence of heteroskedasticity in some cases, performing structural change tests due to Hansen (2000) is also helpful in detecting whether the data used to estimate the conditional models are stationary (i.e., the evidence of structural break based on Andrews (1993) and Andrews-Ploberger's (1994) p-values which cannot be confirmed by the bootstrap method can be an additional evidence against stationarity of the data).

final VAR models include a shift dummy variable in the case of Czech Republic and Portugal (i.e., the dummy variable, respectively, equals one from 1999M3 and 1994M1 onwards). Since a heteroskedasticity corrected bootstrap did not confirm a structural break in the Slovenian nominal exchange rate, it was concluded that the significance of the CUSUM squared test was due to the variance and not parameter instability. Moreover, the included dummy variables in the VAR equations were insignificant. No break was assumed for Slovenia. Similarly, given the outcome of the CUSUM tests for Hungary, and insignificance of the tested dummy variables in VAR equations, no break was assumed for Hungary.

Once estimated with structural breaks taken into account, the results of misspecification tests did not change much (Annex A.3, Table A.3.1). Despite various attempts, normal and constant variance errors could not be obtained for countries in which these problems were initially detected (however, in the case of the Czech Republic, once the dummy variable was included in the model, ARCH errors in the real exchange rate were no longer present)[42]. Since the structural VAR form is derived from the reduced VAR representation (as a one-to-one transformation), the reliability of results from the structural analysis may be dubious. In order to mitigate normality issues, it is important to put some confidence on impulse responses and variance decompositions obtained from the SVAR models. Since, as a consequence of heteroskedastic/ ARCH errors, the structural shocks are not 'purely' exogenous and may depend on the values of variables in the system (i.e., the conditional variance of the nominal or real exchange rate may change with the past values taken by those rates), the White robust variance estimate for the errors or the SVAR-MVGARCH modelling is needed (given data constraints the White robust variance estimate for the errors is preferred over SVAR-MVGARCH estimations)[43].

Small-Sample Bootstrap Confidence Intervals.

Kilian (1998a, 1998b) shows that if the innovations in a VAR system are not normally distributed, standard methods of generating confidence intervals for

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[42] In the cases of the Czech Republic, Slovakia, and Slovenia, dummy variables were also tested for periods of Asian, Czech, and Russian financial/banking crises, as well as for regime changes identified by Reinhart and Rogoff (2002).

[43] The Gauss programming language was used to obtain results presented in this and the next sections.

impulse responses - such as those proposed by Lütkepohl (1990) or Sims and Zha (1995) - bring unsatisfactory results. Following this approach, the bootstrap-after-bootstrap method is implemented. In Kilian's bootstrapping technique, the non-normality of VAR innovations is accounted for through adjustments for the bias in the OLS coefficient estimates of the VAR system. The bias term in the original OLS estimator is approximated by the following procedure:

1) standard nonparametric bootstrap methods are applied to draw 1000 realisations of $\hat{C}^{(i)}$ from the estimated VAR (p) models (i.e., equation (1.4)) ;
2) then, the bias term $bias = E[C - \hat{C}]$ is approximated by $\hat{bias} = 1/1000 \sum \hat{C}^{(i)} - \hat{C}$;
3) next, stationarity correction is applied if the bias-corrected estimates imply that the VAR becomes non-stationary;

Once the stability conditions are satisfied, the biased corrected coefficients are used to generate 2000 new bootstrap replications of $\hat{C}^{(i)}$. These bias-corrected estimates are next used to compute the empirical distribution of impulse responses. Confidence intervals on impulse responses are constructed using modified percentile method of Davidson and McKinnon (1993). The same, biased corrected coefficients are used to calculate confidence intervals for variance decompositions[44].

The nonparametric standard bootstrap method proposed in Step 1 draws on Runkle (1987) - i.e., it generates bootstrap innovations e_t^* by resampling with replacement from the empirical residuals $\hat{e}_t$. Pseudo-data Δy_t^* is constructed with the use of VAR (p) coefficients and is conditional on the vector of initial observations $\Delta y_0^* = \{\Delta y_1^*,...,\Delta y_{25}^*\}$, which are selected randomly with replacement from the original VAR residuals (see Berkowitz and Kilian (1997)). These initial observations are then discarded so that the final pseudo-sample equals to Δy_t^*. Additionally, each

[44] See Kilian (1998a), p.220 for details.

bootstrap loop takes into account the lag order uncertainty resampling by choosing the number of lags in each draw by minimising the AIC criterion. As showed by Kilian (1998b, p. 545) failing to do so leads to misleading inference - i.e. ignoring the lag order uncertainty may seriously undermine the coverage accuracy of bootstrap confidence intervals for impulse responses[45]. His results further suggest that in small and moderate samples the coverage accuracy of bootstrap confidence intervals for VAR impulse response estimates is much closer to the nominal coverage for the AIC criterion than it is for more parsimonious criteria.

White Robust Variance Estimate for the Errors.

As discussed, not taking into account heteroskedasticity in the structural variance decomposition results in bias in the relative importance of random innovations in the forecast error (i.e., it is influenced by past singular events). Since the purpose of the variance decomposition is to identify the importance of shocks which hit the economy regularly and within constant economic structures, it is important to correct for the presence of heteroskedasticity before such structural inference can be conducted. Therefore, in countries where better specification of VAR models could not be achieved, in order to obtain the White robust variance estimate for the errors, e_t, each of the equations in a reduced form VAR system is estimated by WLS instead of OLS (in order to obtain accurate confidence intervals, WLS VAR estimation also replaces OLS in the above described bootstrapping).

In the WLS estimation conducted for the Czech Republic, Italy, Portugal, Slovakia, and Spain the previously heteroskedastic residuals from the estimated reduced form VAR models turned out to be i.i.d.. Unfortunately, in the case of Slovenia the appropriate weights could not be found. Given that single digit inflation in Slovenia was reached only in 1996, the sample was set to start in January 1996. Despite still significant White tests, in this case weights for the WLS estimation could be obtained. Therefore, the final structural analysis for Slovenia was performed on the sample spanning from 1996M1 to 2006M12.

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[45] Because the lag order uncertainty is taken into account, the short-cut proposed by Kilian in step 2a (1998a, p.220) could not be taken. Additional 2000 loops had to be estimated.

Variance Decomposition.

Once the reduced form VAR models were correctly specified, the structural Blanchard and Quah decomposition was executed. Table 1.5.2 shows the contributions of temporary (i.e. nominal) and permanent (i.e. real) shocks to explaining the forecast error variance of nominal and real exchange rates in the Czech Republic, Hungary, Poland, the Slovak Republic and Slovenia. Column I and III in Table 1.5.2 reflect contributions of the real and nominal shocks, respectively, to the forecast variance error of the real exchange rate. Columns V and VII contain the contributions of the same shocks to movements of the nominal exchange rate. Finally, the numbers in columns II, IV, VI and VIII represent the bootstrapped confidence intervals calculated for a particular percentage of variance decomposition.

The results are striking. In the case of Hungary, the Slovak Republic, and Slovenia over 90% of shocks to the real exchange rate are real in nature. In the Czech Republic real shocks explain as much as 88% of the forecast variance error of the real exchange rate. Poland is somewhat different, with a nominal shock playing a substantial role in the variation of its real exchange rate (in the first month, the extent is 40%, which could perhaps be related to the fact that Poland has the largest stock exchange amongst all analysed NMSs). Nevertheless, after a year, the significance of the nominal shock drops significantly, with real shocks explaining approximately 80% of the forecast variance error of a Polish real exchange rate. The dominance of real shocks in the real exchange rate fluctuations confirms the finding of the unit root tests which suggest that real rates are not stationary.

Variance decomposition of nominal exchange rates is more heterogeneous. Nominal shocks overwhelmingly dominate the variation of the Slovenian tolar (over 80% of movements are due to this type of shocks), and are an important part of the volatility of the Polish zloty (around 50% irrespective of the forecast horizon), the Czech koruna (on average 30% within the first three months), the Hungarian forint (which despite a very minimal initial impact, after a year increases to around 20% and higher) and to some extent the Slovakian koruna (which remains around 15% after a year).

Table 1.5.2 Variance Decomposition (NMSs)

Variable	RER				NER			
Variance Decomposition	RER shock		NER shock		RER shock		NER shock	
CZECH REP.	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
1-month	87.8	60.2-100	12.2	0.0-39.8	62.8	23.1-100	37.2	0.0-76.9
3-month	91.9	72.0-100	8.1	0.0-28.0	70.1	35.3-99.7	29.9	0.3-64.7
12-month	95.0	82.1-100	5.0	0.0-17.9	76.0	47.5-99.6	24.0	0.4-52.5
24-month	97.5	90.3-100	2.5	0.0-9.7	80.9	58.7-97.6	19.1	2.4-41.3
60-month	99.5	98.0-100	0.5	0.0-2.0	86.0	71.0-99.0	14.0	1.0-29.0
HUNGARY								
1-month	99.5	58.6-100	0.5	0.0-41.4	96.9	38.0-100	3.1	0.0-62.0
3-month	99.8	57.6-100	0.2	0.0-42.4	93.6	33.0-100	6.4	0.0-67.0
12-month	99.5	69.1-100	0.5	0.0-30.9	83.0	23.7-99.5	17.0	0.5-76.3
24-month	99.7	80.2-100	0.3	0.0-19.8	72.4	18.2-98.9	27.6	1.1-81.8
60-month	99.8	91.5-100	0.2	0.0-8.5	60.8	7.8-94.4	39.2	5.6-92.2
POLAND								
1-month	60.6	26.1-100	39.4	0.0-73.9	47.1	15.0-100	52.9	0.0-85.0
3-month	69.1	36.1-100	30.9	0.0-63.9	53.1	20.1-100	46.9	0.0-79.9
12-month	82.9	64.8-100	17.1	0.0-35.2	49.9	24.6-98.2	50.1	1.8-75.4
24-month	90.4	81.2-100	9.6	0.0-18.8	45.7	23.6-94.2	54.3	5.8-76.4
60-month	96.3	93.5-100	3.7	0.0-6.5	40.4	25.0-95.7	59.6	4.3-75.0
SLOVAK REP.								
1-month	100	86.2-100	0.0	0.0-13.8	74.1	41.0-100	25.9	0.0-59.0
3-month	99.6	88.5-100	0.4	0.0-11.5	78.4	48.0-100	21.6	0.0-52.0
12-month	99.9	96.5-100	0.1	0.0-3.6	84.4	63.1-97.0	15.6	3.0-36.9
24-month	100	98.2-100	0.0	0.0-1.8	85.2	66.5- 97.3	14.8	2.7- 33.5
60-month	100	99.3-100	0.0	0.0-0.7	85.7	67.3 97.2	14.3	2.8- 32.7
SLOVENIA								
1-month	95.4	38.9-100	4.6	0.0-61.1	14.9	0.0-81.6	85.1	100-18.4
3-month	89.9	39.3-100	10.1	0.0-60.7	22.2	0.0-87.0	77.8	100-13.0
12-month	92.9	56.7-99.9	7.1	0.1-43.3	8.1	3.3-65.2	91.9	96.7-34.8
24-month	95.5	74.6-99.9	4.5	0.1-25.4	3.8	0.9-61.9	96.2	99.1-38.1
60-month	98.0	90.3-100	2.0	0.0-9.7	4.3	0.3-66.9	95.7	99.7-33.1

Note: Column I and III reflect contributions of the real and nominal shocks, respectively, to the forecast variance error of the real exchange rate; columns V and VII contain the contributions of the same shocks to movements of the nominal exchange rate; the numbers in columns II, IV, VI and VIII represent the bootstrapped confidence intervals calculated for a particular percentage of variance decomposition.

Source: Author’s estimation based on IMF IFS and EUROSTAT data.

With regard to the OMSs (Annex A.4, Table A.4.1), there is no doubt that real shocks are responsible for real exchange rate movements in all countries but Spain, where at the 3-month forecast horizon, a nominal shock explains 10 percent of real exchange rate volatility. Real shocks also move nominal exchange rates in Germany and France and to the lesser extend in Italy. For Greece, the nominal shock is persistent and amounts to around 30 percent of the nominal exchange rate volatility for all forecast horizons. For Portugal it remains at the 20 percent level. For Spain it drops to around 15 percent already after a year. Interestingly, despite the fact that all countries included in the OMS group except for Germany adopted some form of *de facto* pegged exchange rate regime to the DM, relatively little distortion caused by that fact seems to arise. The temporary component in the real exchange rate forecast error variance in all the countries is virtually nonexistent.

Impulse Responses.

Overall the shocks seem to be well identified, i.e. the restrictions imposed on $\Theta(1)$ make it possible to obtain impulse response functions (in response to structural innovations), which are consistent with an economic theory. As required by the identification assumption, in all cases, the one unit impact of the nominal shock on the real exchange rate is temporary (see Figure 1.1 below). Testing the hypothesis that a positive nominal shock has a proportional, long-run, effect on a nominal exchange rate (i.e., imposing the restriction D(2,2)=1) brought mixed results, but overall showed that a positive nominal shock leads to currency depreciation (i.e., D(2,2) is always positive, see Table 1.5.3).

Table 1.5.3 Test of Long-Run Over-identifying Restrictions

	L_BAND	D(2,2)	U_BAND
Czech Rep.	0.18	**0.40**	0.50
Hungary	0.74	**3.84**	4.24
Poland	0.61	**2.02**	2.43
Slovakia	0.13	**0.67**	0.87
Slovenia	0.16	**0.72**	0.46

Note: Columns L_Band and U_Band stand for the lower and upper band, respectively, of 90% bootstrapped confidence intervals.

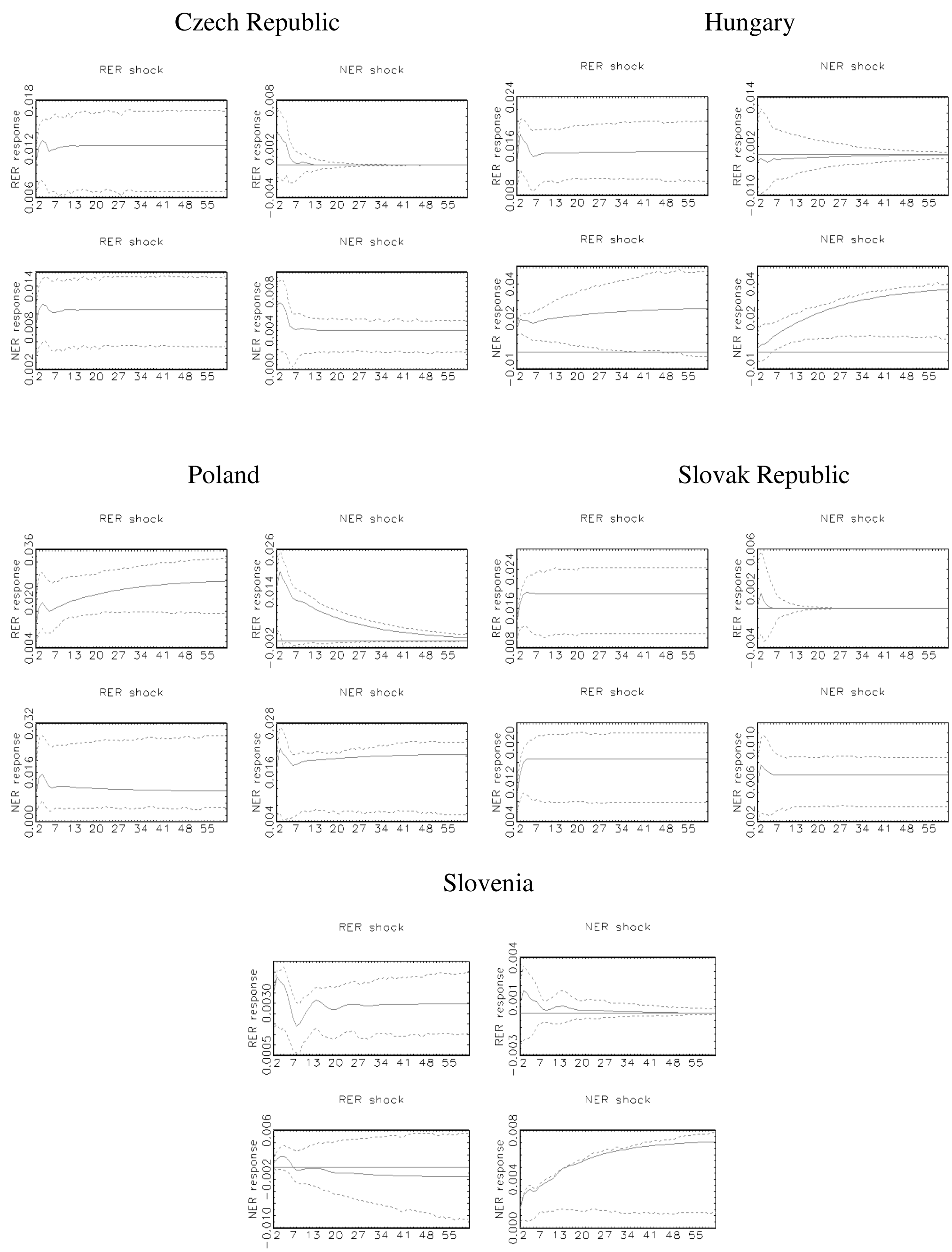
Source: Author's estimation based on IMF IFS and EUROSTAT data.

This effect is less than proportional in the case of the Czech Republic, Slovakia and Slovenia. Despite the fact that the overshooting effect is present in Poland and Hungary[46], the bootstrapped 90% confidence bands are rather wide. Finally, a positive real shock, in all countries, causes long-run nominal and real exchange rate depreciation (perhaps with the exception of Slovenia, where the real exchange rate appreciates over time). This provides some evidence against the 'exchange rate disconnect' theory – if nominal exchange rate movements were fully passed-through to the general consumer price index (i.e., they were fully offset by relative price changes), the real exchange rate would be constant. In this case, the nominal exchange rate flexibility would not be able to bring about the expenditure-switching mechanism. The remainder of this section deals with individual country cases[47]:

[46] The D(2,2) coefficient is significantly above 1. Also, as figures showing the impact of the nominal shocks on nominal exchange rates in these countries indicate (see Figure 1.1), following the shock, nominal exchange rates never return to their initial values.

[47] Impulse responses for the OMSs, as they are of little relevance for the study, are available upon request.

Figure 1.1 Impulse Responses (NMSs)



Note: RER – real exchange rate, NER - nominal exchange rate. The top two, out of four, panels presented for each country represent impulse responses of the RER to a unit of real and nominal shocks, respectively; the bottom two panels are impulse responses of the NER to a unit of real and nominal shocks, respectively.

Source: Author's estimations based on IMF IFS and EUROSTAT data.

Czech Republic

In the Czech Republic, following a real shock, the real exchange rate jumps in the same direction but more than the nominal rate. After the initial jump, both rates return to their long-run values (0.0124 and 0.0106) within eleven and nine months, respectively. Given that the response of the real rate is larger than the response of the nominal rate indicates that permanent changes to the real exchange rate occurs through both the nominal exchange and the relative price. The fact that the nominal rate depreciates less in response to a real shock than the real rate does, indicates that the domestic relative price falls. One possible explanation of this outcome is that real shocks are supply-side shocks. The fact that the RER depreciates and not appreciates in response to the real shock in the Czech Republic does not support the hypothesis that the downward trend in the RER could be associated with a HBS effect in this country. It could be that either, the HBS effect is simply not responsible for the appreciating RER in this country. However, it could also be that the bivariate SVAR model is simply not capturing all sources of fluctuations with permanent effects on the RER[48]. Along with the imposed identification restriction (D(1,2)=0), a nominal shock has no long-run effect on a real exchange rate. In the short-run, the real exchange rate increases, but this effect is not large and approaches zero in less than a year. In response to the nominal shock, the nominal exchange rate jumps away from zero, but the jump is of a very small and short-lasting magnitude, casting doubts about its significance. Finally, because nominal shocks have no long-run effects on real rates, and since nominal shocks do affect real exchange rate to some degree, nominal shocks have to affect prices by an equal but opposite amount (with some evidence of price sluggishness in the short-run).

Hungary

In Hungary, real shocks cause a long-term depreciation of both real and nominal exchange rates, indicating that the nominal exchange rate does absorb shocks which cause real exchange rate movements. The fact that the nominal rate depreciates more in response to a real shock than the real rate does, indicates that - in response to

[48] Faust and Leeper (1997) make the point that if one identified structural shock consists of two independent shocks, then the BQ-SVAR methodology is valid only if the underlying macroeconomic variables respond to the two shocks in the same direction.

positive real shocks - domestic prices go up. One possible explanation of this outcome is that real shocks are demand-side shocks. In particular, given high and prolonged budget deficits in Hungary, this dynamic could be a result of fiscal shocks. Similar to the case of the Czech Republic, there is no evidence of the HBS effect in Hungary. In response to a nominal shock, after the initial (very minimal) appreciation, the real exchange rate comes back to the zero line – as predicted by the identification restriction (the effect does not last more than a year). On the other hand, following the nominal shock, the nominal exchange rate depreciates substantially and this depreciation is permanent. Because the movements of the RER is almost negligible when compared with the movements of the nominal exchange rate in response to the nominal shock, a possible explanation of those movements is that variations in the nominal exchange rate are due to monetary shocks, which cause proportional but inverse changes in domestic prices (with some evidence of overshooting as RER appreciates in the short-run). Notice that for the RER to appreciate when nominal rate deprecates, relative prices must appreciate as well.

Poland

In Poland, as in previous cases, a real shock causes real and nominal exchange rates to depreciate. The fact that real exchange rate depreciates in response to the tradable productivity shock casts doubts about the presence of the HBS effect also in this country. The adjustment path for the real rate nevertheless differs from that of the nominal rate. Following the real shock, the real rate goes through a brief period of revaluation relative to the initial depreciation. After a year a steady depreciation is observed. This indicates that the shock could be related to positive productivity improvements, which are associated with price decreases. In the case of the nominal rate, the final depreciation is lower than the initial response. The fact that the real exchange rate depreciates more than the nominal rate in response to the real shock, suggests that a positive real shock causes domestic prices to decline and thus improves the country's price competitiveness (as in the case of Czech Republic). In response to a nominal shock a real exchange rate overshoots its long-run value. The impact is long lasting. Were nominal shocks monetary in nature, this would indicate that monetary policy can influence both real and nominal exchange rates. Nevertheless, in the short-run, the response of the real exchange rate to a real shock is greater. The same is not true for the nominal exchange rate. The response of the Polish zloty to a nominal shock is greater than it is to a real shock; there is also evidence of moderate ‘overshooting’ (although less so than in Hungary). However, the nominal exchange rate reaction function indicates that the nominal exchange rate achieves its new long-run level in less than a year.

The Slovak Republic

An interesting feature of the impulse response analysis conducted for the Slovak Republic is that, although the magnitudes are somewhat different, the shapes of reaction functions are the same for the real and nominal exchange rates in response to a real and nominal shock, respectively. In the short-run, the real exchange rate depreciates more in response to the real shock than the nominal exchange rate does. Again, as in cases of Czech Republic and Poland, this indicates an improvement in the country’s price competitiveness and brings no support for the HBS effect. Looking at the effects of nominal shocks on real and nominal exchange rates, it is hard to see any significant evidence of overshooting. Even if both rates do move in response to nominal shocks affecting them, the jump is less than proportional (this is confirmed by the 90% confidence bands) and relatively small.

Slovenia

In Slovenia, the impulse response functions of real and nominal exchange rates are different depending on the shock hitting the economy. In response to a real shock, initial fluctuations of the real exchange rate are observed. The long-run value is only modestly higher when compared with the ‘starting’ level. As the real shock causes a long-run moderate appreciation of the nominal exchange rate, and the real exchange rate is almost constant, this suggests that the nominal rate has been moving in the opposite direction to the relative price. In response to a nominal shock, the real exchange rate jumps above its long run value, but the jump does not seem to be significant. The nominal exchange rate does not jump, but rather depreciates steadily**.** This is in line with the accommodative exchange rate policy geared at stabilizing real exchange rate conducted by Slovenian authorities – i.e. following a shock which results in price changes, in order to keep the real exchange rate constant, nominal depreciation is required (see also footnote 22). Given this discretionary exchange rate policy in Slovenia, it is also not surprising that the nominal shock dominates nominal exchange rate movement (i.e., nominal shocks can be most likely interpreted as monetary policy shocks in this country). Overall, the scale of impulse responses in Slovenia, with the exception of the response of the nominal rate to the nominal shock, is minimal.

Robustness Checks.

Since the Faust and Leeper (1997) critique relating to the potential invalidity of imposing long-run restrictions to the finite sample is particularly important for VAR models with a large lag order, it is important to check the robustness of the performed structural VAR analysis. As showed by Lastrapes (1998) the robustness checks can be performed by re-estimating the bivariate SVAR model with the identifying restrictions imposed at different finite horizons. Annex A.3, Figure A.3.2, sets out the results of this analysis, and shows that impulse responses change very little in terms of original dynamics. Therefore, the structural VAR analysis can be said to be robust to the Faust and Leeper's (1997) critique, and that the horizon of 60 months can sufficiently approximate the long-run[49].

1.6 CONCLUSIONS

Based on the results obtained from the univariate variance analysis as well as the structural VAR, the following comments and conclusions about the real convergence process in the NMSs of the EU can be drawn.

As the estimates show, based on the proposed definition of real convergence, to lessen the costs of the eurozone membership, the levels of volatility in the NMSs will have to be reduced (with the exception of Slovenia[50] and Estonia). This is because, despite the progress in real convergence, average volatility for the NMSs is currently 1.9 times higher than the average volatility of the selected OMSs analysed in this chapter in the mid-1990s (1.5 higher than it was for the average of Club Med

[49] The results for the OMSs are available upon request.
[50] As Slovenia is already in the eurozone, it can be said that – based on the proposed indicator – it was ready to give up its monetary and exchange rate policy and should benefit from the euro adoption.

countries and 3.5 times higher than the average estimated for France and Germany). The plots of the estimated quarterly time varying conditional variances for real exchange rates seem to support these findings.

The fact that real shocks dominate real exchange rate movements implies that the univariate analysis undertaken in this chapter provides an accurate measure of real exchange rate variance (at least for countries for which VAR analysis was possible). Given the moderate impact of nominal shocks to real exchange rate variability at the 3-month forecast horizon, it is not implausible to assume that monthly and quarterly volatility changes represent the 'true' magnitude of real convergence in these countries. However, due to the presence of nominal shocks, in the case of Poland, monthly and quarterly real exchange rate volatility should be scaled down by approximately 40 and 31 percent, respectively; in the case of the Czech Republic by 12 and 8 percent. Likewise, because the variance decomposition for the Club Med countries as well as France and Germany shows that real shocks dominated real exchange rates in these countries, the benchmark magnitudes for real convergence can be treated with confidence.

Although at the time of writing Estonia does not fulfil the nominal Maastricht inflation criterion, it seems that – based on the proposed definition – it could benefit from full integration into the EMU. Given that Estonia has managed to cope without monetary independence for over ten years, and given its comparatively flexible labour and product markets, Estonia could benefit from the euro adoption[51]. As for the rest of the countries, more effort is needed in reducing idiosyncratic real shocks. The proposed indicator for real convergence, ex post, does not support Slovakian admission into the eurozone in January 2009. Giving up monetary independence may be premature because existing asymmetries are not insignificant, and in fact are higher than those observed in the Czech Republic, Latvia and Lithuania (in the third sub-sample). Finally, analysis in the case of Poland, once real exchange rate volatility is scaled down for the presence of nominal shocks, imply that the country

[51] Moreover, the policies needed to target current imbalances, in the currency union, would not be different to those required under a currency board. At the same time Estonia could enjoy the benefits of the common currency.

has achieved a level of real convergence with the eurozone comparable to other countries in the NMSs' group[52].

The structural VAR analysis showed that in all countries except for Slovenia, for which it was possible to estimate VAR models, the nominal exchange rate does move in the same direction as the real exchange rate at the onset of a real shock, and thus does play a shock-stabilising role. Therefore, loss of the nominal exchange rate as an adjustment instrument would represent a cost of the euro area membership.

In the case of Poland (and to a lesser degree in the Czech Republic), the importance of nominal shocks in the real exchange rate forecast error variance does not indicate that there is no cost in losing the nominal exchange rate as an adjustment instrument. This is because nominal shocks seem not to be destabilizing (similarly to other investigated countries), indicating that there is still some room for short-run effectiveness of monetary and exchange rate policy in changing the real exchange rate in this country. However, it is also true that more stable monetary policy could result in a greater real exchange rate stability[53].

The results of the Blanchard and Quah variance decomposition show that the nominal component of nominal exchange rate movements in the five countries included in the SVAR modelling is not insignificant (perhaps to a lesser degree in the case of Slovakia)[54]. Therefore, elimination of these movements could be a positive benefit of speedy accession to the euro area. However, given the need to fulfil Maastricht criteria first, and the relatively significant degree of real asymmetry, there may be risks to premature ERMII participation (i.e. due to increased capital flows or consumption booms). Additionally, significant nominal exchange rate responses to real shocks in all five NMSs except for Slovenia need to be analysed

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[52] In the case of Poland, without the SVAR analysis, the univariate approach would produce distorted results.
[53] The possibility of effectiveness of monetary and exchange rate policies in changing Polish competitiveness was also concluded by Dibooglu and Kutan (2001). However, in their study, a nominal shock dominates a real exchange rate forecast error variance to a greater degree.
[54] The nominal exchange rate volatility in the OMSs was mainly driven by real factors (to the lesser degree in Spain and Greece).

and taken into account in assessing nominal exchange rate stability at the end of the ERMII period[55].

Finally, given (i) that real asymmetric shocks are not insignificant when compared with the Club Med countries, (ii) the stabilising role of nominal exchange rates (with the exception of Slovenia), and (iii) the fact that nominal shocks, on average, do not move real exchange rates, the NMSs may be well advised to take their time in joining the eurozone (except for Estonia and Slovenia (ex post)). In the interim they may do well to concentrate on enhancing structural reforms, until they are ready to give up monetary and exchange rate independence.

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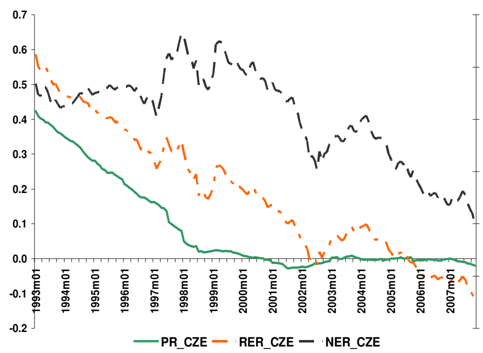
[55] Given the broad classification of shocks, at this stage, without further identification of shocks, it is impossible to investigate the split between supply and demand shocks.

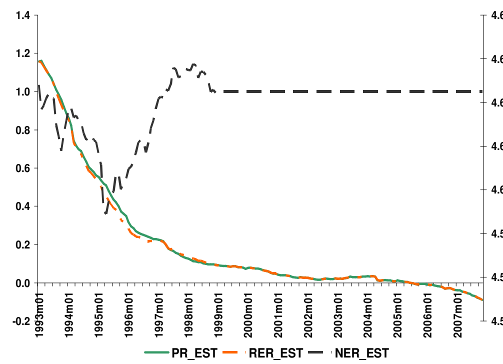
ANNEX A.1 GRAPHICAL PRESENTATION AND INTEGRATION PROPERTIES

Figure A.1.1 Exchange Rates and Price Ratio Developments in the NMSs

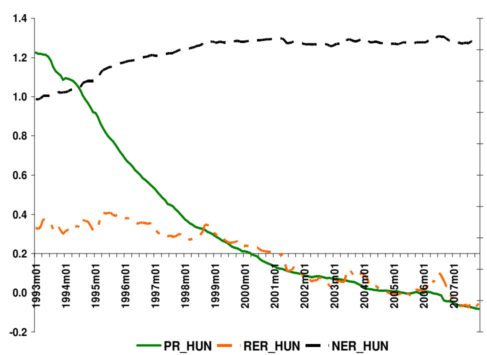
Czech Republic



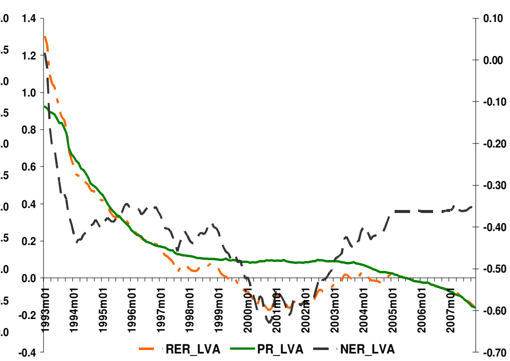
Estonia



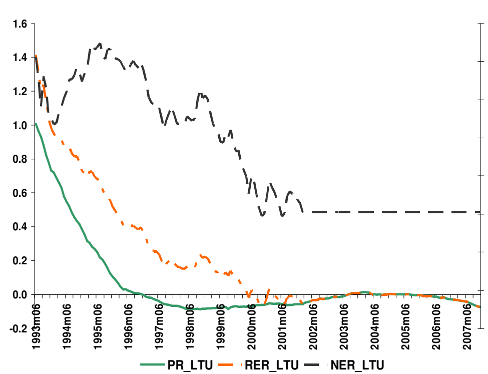
Hungary



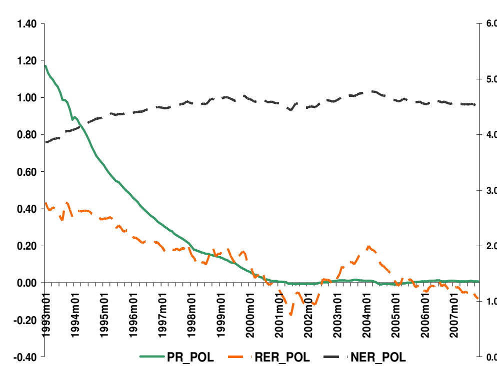
Latvia



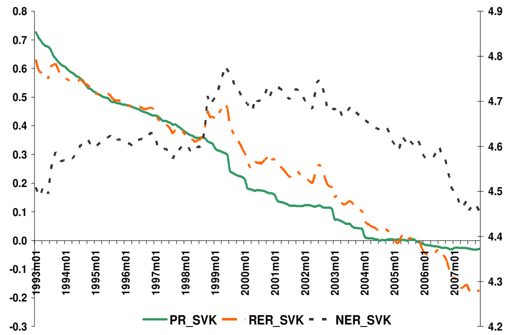
Lithuania



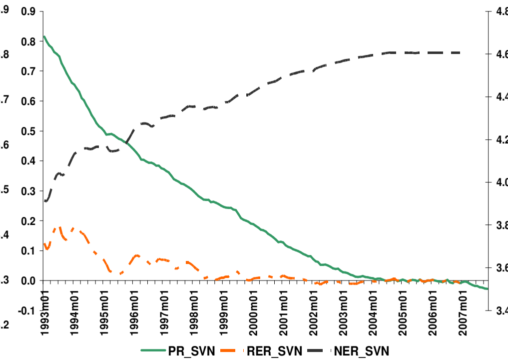
Poland



Slovak Republic



Slovenia



Note: The magnitudes of relative prices and real exchange rates' indices are on the LHS axis; the magnitudes of nominal exchange rates' indices on the RHS axis. Indices are defined with the base of 2005=100. Decrease in the exchange rate index indicates appreciation.

Source: Author's calculation based on data from the Eurostat and IMF IFS.

Table A.1.1 Properties of Real Exchange Rates in a Data (NMSs)

FULL SAMPLE	Czech Rep.	Estonia	Hungary	Latvia	Lithuania	Poland	Slovak Rep.	Slovenia
Persistance								
Nominal Exchnage Rate	0.19	0.27	0.36	0.47	0.18	0.33	0.27	0.70
t-stat	2.58	3.83	5.11	7.11	2.42	4.66	3.73	12.86
Real Exchange Rate	0.14	0.69	0.24	0.53	0.37	0.27	0.22	0.53
t-stat	1.94	12.68	3.30	8.43	5.59	3.71	3.02	8.28
Cross-Correlations								
Real and Nominal Exchnage Rates	0.94	0.31	0.92	0.91	0.83	0.91	0.89	0.77

Source: Author's calculation based on IMF IFS and EUROSTAT data.

Table A.1.2 Unit Root Tests

	DF-GLS			MZt			MZa			KPSS		
	NER	RER	PR	NER	RER	PR	NER	RER	PR	NER	RER	PR
CZE	-0.9	-1.6	-1.1	-0.9	-1.7	-1.4	-2.4	-5.8	-4.8	…	…	…
EST	…	-2.1	…	…	-1.0	…	…	-2.4	…	…	…	…
HUN	-0.9	-1.8	-0.9	-1.1	-1.8	-1.5	-3.2	-6.5	-5.5	0.4	…	…
LTU	…	-0.3	…	…	-0.1	…	…	-0.1	…	…	…	…
LVA	…	-0.4	…	…	-0.4	…	…	-0.5	…	…	…	…
POL	-0.2	-1.7	-1.7	-0.2	-1.7	-0.8	-0.3	-5.8	-2.0	…	…	…
SVK	-0.5	-2.6	0.1	-0.5	-2.5	0.1	-1.3	-13.8	0.3	…	…	…
SVN	-0.2	**-3.0**	-0.5	-0.3	**-3.0**	-0.7	-0.5	**-18.1**	-1.8	0.3	0.3	…
FRA	-2.0	-2.2	-1.1	-1.9	-2.1	-0.9	-7.0	-8.7	-1.9	…	…	0.2
DEU	-1.5	-1.6	-1.6	-1.5	-1.6	-1.5	-4.6	-5.0	-4.7	…	…	…
ESP	-1.2	-1.4	-1.3	-1.0	-1.1	-0.6	-2.3	-2.7	-1.2	…	…	…
GRC	-1.7	-2.0	-0.4	-1.7	-2.1	-0.5	-6.3	-9.1	-1.1	…	…	…
ITA	-1.5	-1.5	-0.8	-1.5	-1.5	-0.8	-5.0	-4.9	-1.8	…	…	…
PRT	-1.1	-1.2	-1.5	-0.8	-0.9	-1.5	-1.5	-2.1	-4.3	…	…	…

Note: NER - nominal exchange rate; RER – real exchange rate; PR – price ratio. Bolden magnitudes indicate significant tests at the 5 per cent level; i.e., stationarity of exchange rate or/and price ratio series in levels; kmax=int(12*(T/100)^(0.25)), where kmax stands for the maximum augmentation lags allowed for.

Source: Author's calculation based on IMF IFS and EUROSTAT data.

Table A.1.3 Unit Root Test with a Break

Perron (1997)	NER								NER					
	_CZE	_EST	_HUN	_LTU	_LVA	_POL	_SVK	_SVN	_FRA	_DEU	_ESP	_GRC	_ITA	_PRT
Break point	77.0	n/a	64.0	n/a	n/a	54.0	109.0	110.0	65.0	65.0	14.0	24.0	29.0	14.0
Dummy_coeff.	0.0	n/a	0.0	n/a	n/a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-stat	-22.2	n/a	-53.2	n/a	n/a	-23.7	-27.9	-17.9	0.5	0.6	-12.5	-9.3	-10.6	-10.3
Trend_coeff.	0.0	n/a	0.0	n/a	n/a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-stat	9.4	n/a	72.1	n/a	n/a	29.6	23.1	66.0	-0.8	3.1	15.0	15.7	11.0	11.8
Fixed lag	10.0	n/a	11.0	n/a	n/a	11.0	1.0	7.0	0.0	7.0	7.0	5.0	8.0	9.0
y(a-1)	-0.1	n/a	-0.2	n/a	n/a	-0.1	-0.1	-0.1	-0.1	-0.1	-0.4	-0.3	-0.2	-0.2
ADF	-3.0	n/a	**-4.4**	n/a	n/a	-3.4	-3.7	-5.1	-2.2	-1.7	-3.7	-3.4	-2.7	-2.9
	RER								RER					
Break point	161.0	161.0	33.0	157.0	161.0	161.0	113.0	151.0	65.0	65.0	14.0	14.0	28.0	14.0
Dummy_coeff.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-stat	2.6	3.6	-11.2	4.6	3.1	1.9	-13.0	4.4	0.1	0.4	-9.3	0.9	-9.3	-6.5
Trend_coeff.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-stat	-56.9	-18.6	4.9	-20.5	-15.0	-18.7	-46.2	-18.7	6.3	6.0	10.0	-2.0	7.5	6.1
Fixed lag	10.0	13.0	10.0	12.0	8.0	10.0	11.0	7.0	0.0	7.0	1.0	5.0	7.0	7.0
y(a-1)	-0.1	0.0	-0.1	0.0	0.0	0.0	-0.2	-0.1	-0.1	-0.1	-0.2	-0.1	-0.2	-0.2
ADF	-2.4	-2.2	-3.3	-1.7	-2.1	-2.5	-4.0	-3.1	-2.4	-1.7	-3.1	-2.0	-2.2	-3.1
	PR								PR					
Break point	161.0	n/a	161.0	n/a	n/a	161.0	18.0	151.0	24.0	44.0	65.0	86.0	14.0	65.0
Dummy_coeff.	0.0	n/a	0.0	n/a	n/a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-stat	5.8	n/a	6.0	n/a	n/a	6.1	7.0	9.2	-15.4	-7.7	4.0	6.6	2.0	-1.1
Trend_coeff.	0.0	n/a	0.0	n/a	n/a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T-stat	-23.0	n/a	-35.6	n/a	n/a	-23.1	-11.2	-52.2	29.0	17.4	-31.1	-39.7	-6.2	-27.6
Fixed lag	10.0	n/a	3.0	n/a	n/a	13.0	12.0	13.0	0.0	9.0	9.0	4.0	9.0	1.0
y(a-1)	0.0	n/a	0.0	n/a	n/a	0.0	0.0	0.0	-0.5	-0.3	-0.1	0.0	-0.1	-0.1
ADF	-2.1	n/a	-2.5	n/a	n/a	-2.6	-1.1	-2.6	**-4.9**	-4.2	-2.0	-2.7	-2.6	-2.6

Note: NER - nominal exchange rate; RER – real exchange rate; PR – price ratio. kmax=int(12*(T/100)^(0.25)), where kmax stands for the maximum augmentation lags allowed for. In the first column, 'Break point' indicates the position of the structural break. 'Dummy_coeff' stands for the estimated coefficient on the break dummy variable. 'Trend_coeff' stands for the estimated time trend coefficient. The lines 'T-stat' present t-statistics of the break dummy and time trend coefficients, respectively. In the line 'Fixed lag', the selected number of lags is reported. The 'y(a-1)' line stands for the estimate of the autoregressive parameter. Finally, 'ADF' is an ADF t-statistic (i.e. t-statistics on the autoregressive parameter).

Source: Author's calculation based on IMF IFS and EUROSTAT data.

Table A.1.4 Significance of Volatility Changes: NMSs

Country	White Heteroskedasticity		ARCH		
	93-98	96-07	93-98	96-07	93-07
Czech Republic	**0.00**	0.13	**0.01**	**0.00**	**0.04**
Estonia	0.00	**0.00**	0.47	**0.01**	**0.00**
Hungary	0.75	0.98	0.77	**0.00**	**0.05**
Latvia	0.27	**0.08**	**0.06**	**0.01**	**0.03**
Lithuania	0.95	**0.00**	0.13	**0.00**	**0.00**
Poland	0.88	0.23	**0.03**	0.18	0.24
Slovakia	0.75	0.16	0.37	0.71	**0.00**
Slovenia	**0.08**	**0.00**	0.36	**0.01**	**0.00**

Note: Columns 'White Heteroskedasticity' and 'ARCH' report p-values of the conducted heteroskedasticity and ARCH tests on the residuals obtained from the OLS estimated regressions of real exchange rate changes on their own lags in the two sub-samples, 1993-1998 and 1996-2007. Bolden magnitudes indicate significant values at the 10% significance level.

Source: Author's calculation based on IMF IFS and EUROSTAT data.

Table A.1.5 Significance of Volatility Changes: OMSs

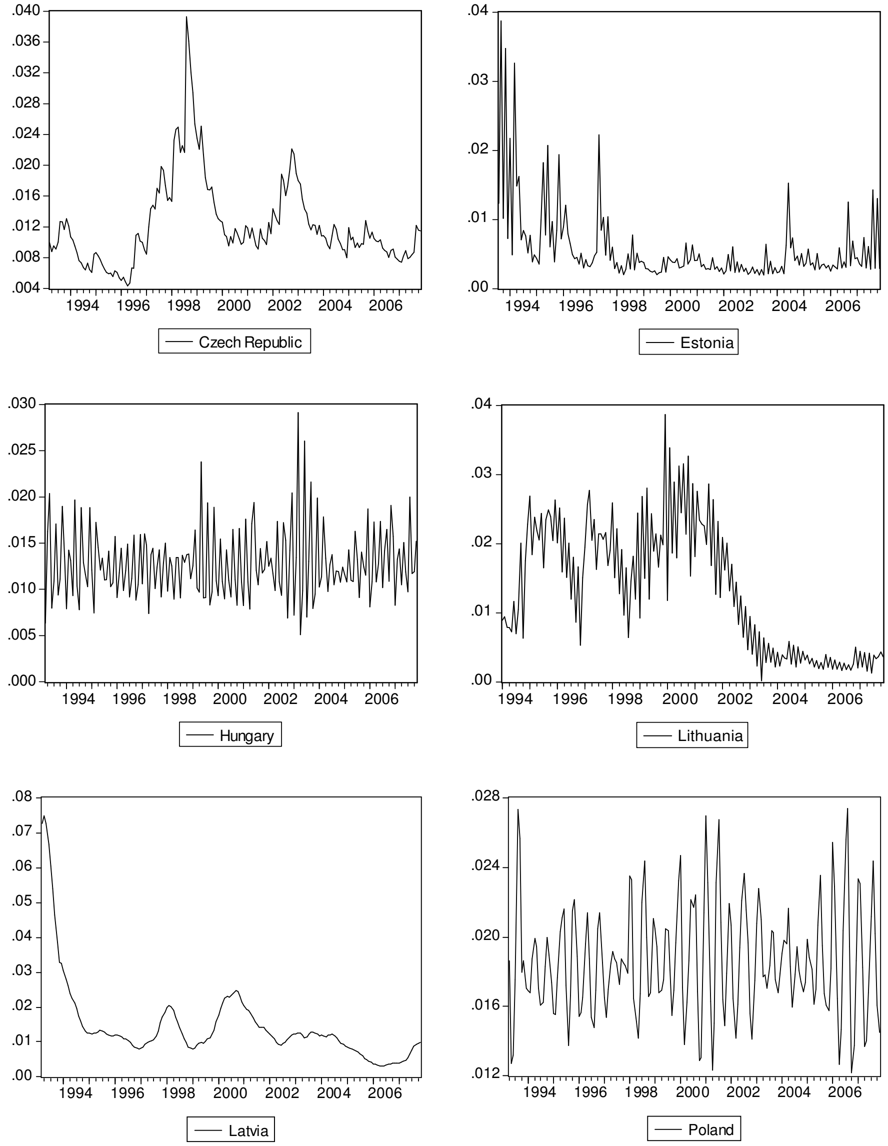
Country	White Heteroskedasticity	ARCH
Germany	**0.01**	0.15
France	**mean_eq**	**0.01**
Italy	**0.00**	**0.07**
Greece	0.94	**0.04**
Portugal	**0.03**	**0.10**
Spain	0.88	0.51

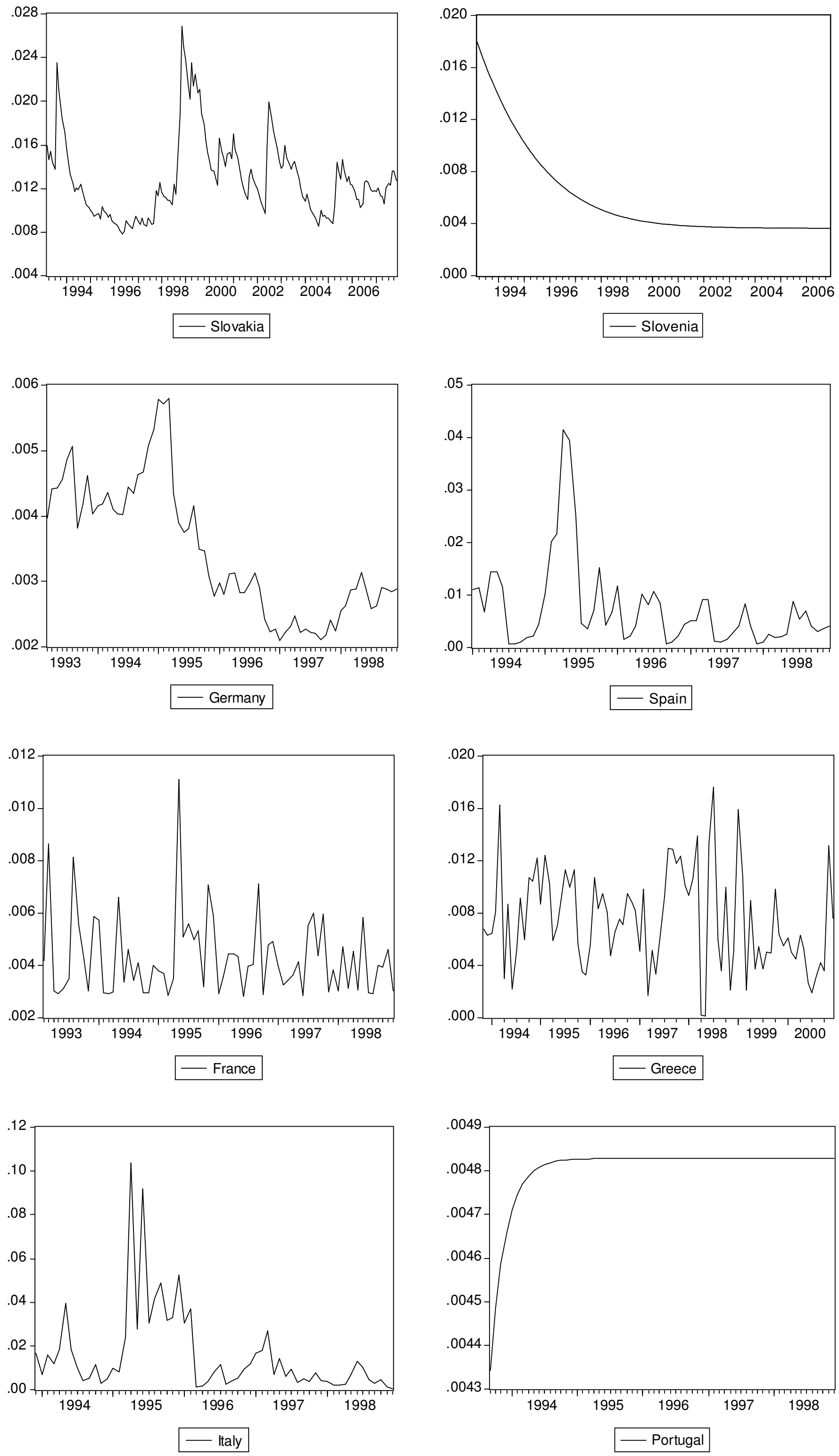
Note: Columns 'White Heteroskedasticity' and 'ARCH' report p-values of the conducted heteroskedasticity and ARCH tests on the residuals obtained from the OLS estimated regressions of real exchange rate changes on their own lags in the whole samples, 1993-1998. Bolden magnitudes indicate significant values at the 10% significance level.

Source: Author's calculation based on IMF IFS and EUROSTAT data.

ANNEX A.2 TIME VARYING CONDITIONAL VARIANCES (REAL EXCHANGE RATES)

Figure A.2. 1 Time Varying Conditional Variances (NMSs, OMSs, Monthly)

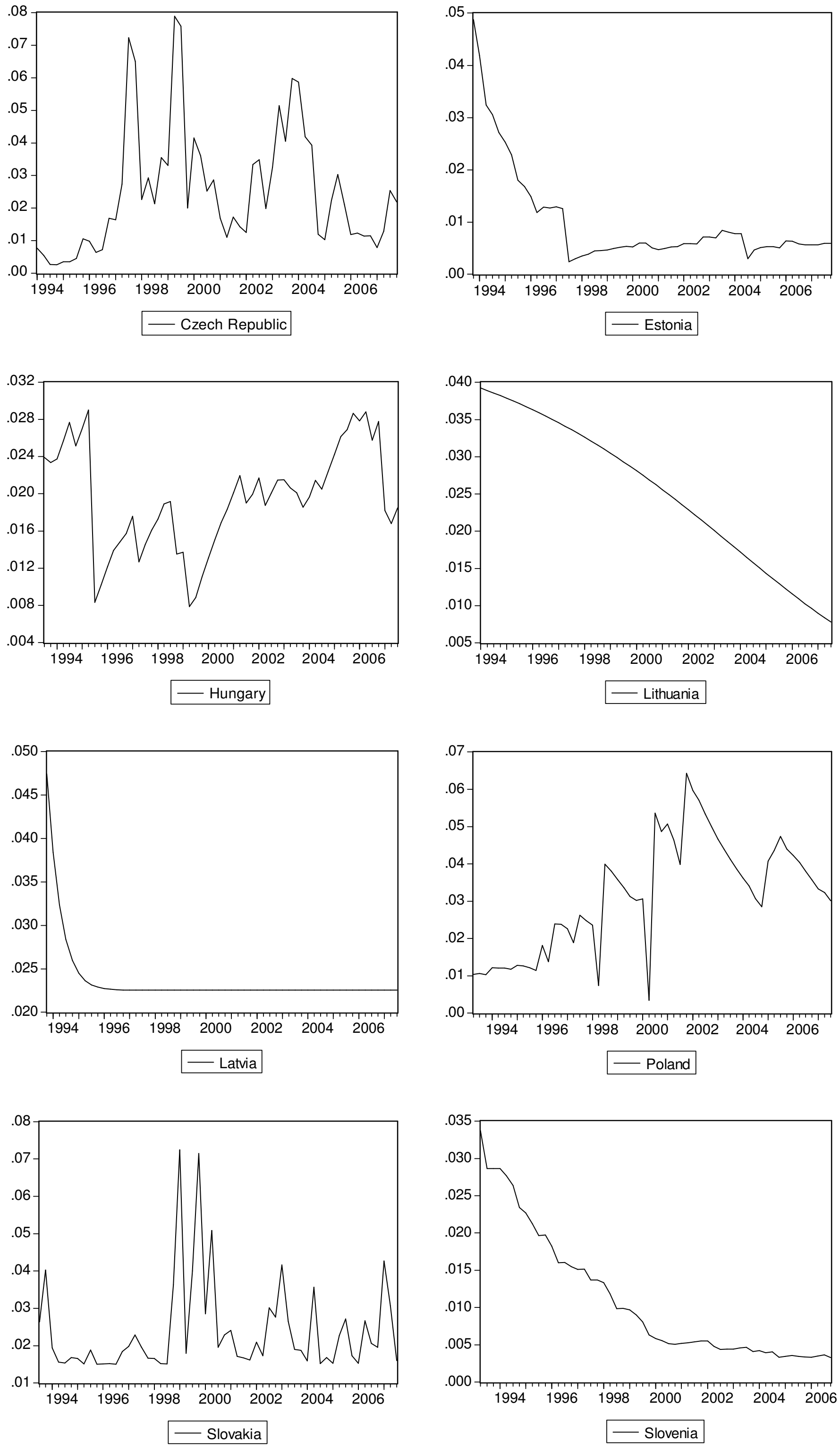


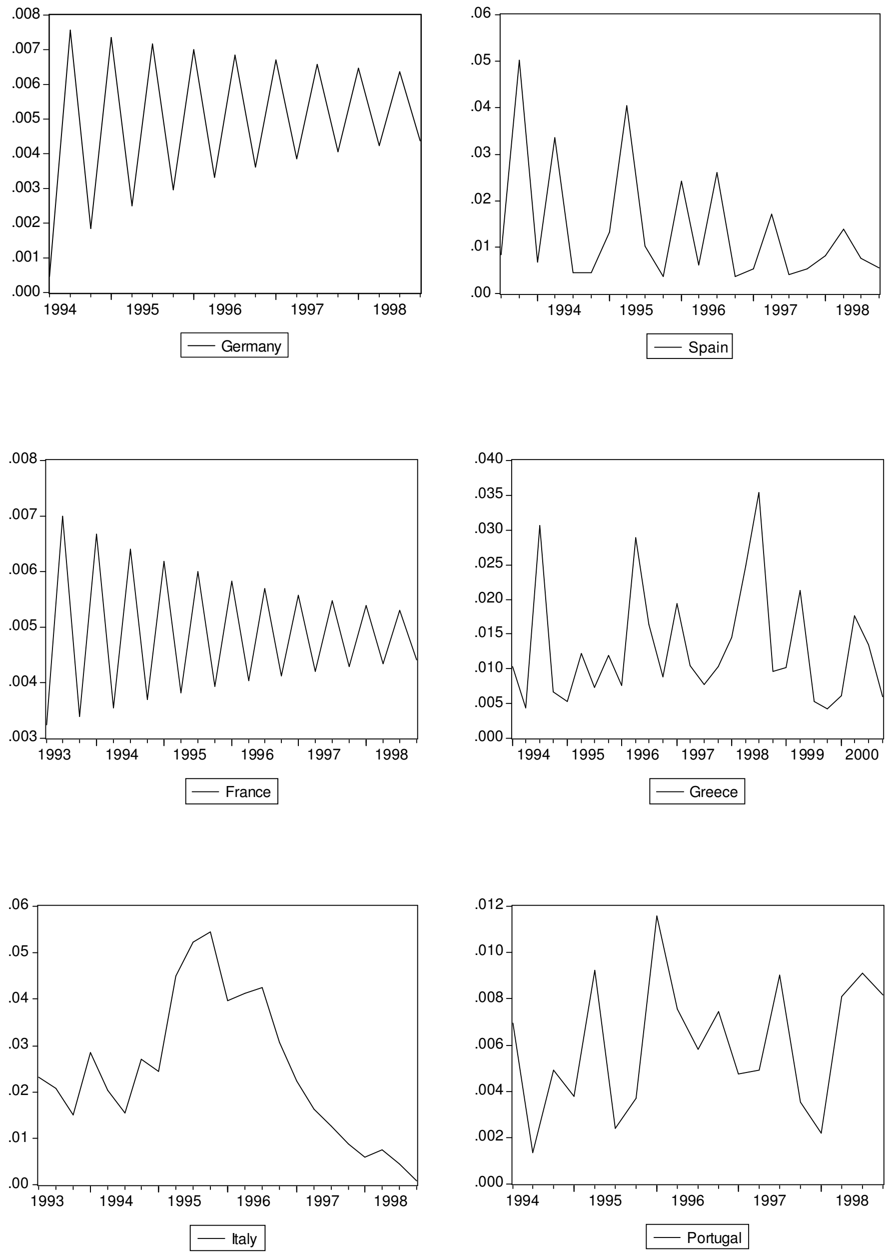


Note: Vertical axis present one-step ahead standard deviation σt for each observation in the sample.

Source: Author's calculation based on the IMF IFS and EUROSTAT data.

Figure A.2.2 Time Varying Conditional Variances (NMSs and OMSs, Quarterly)





Note: Vertical axis present one-step ahead standard deviation σ_t for each observation in the sample.

Source: Author's calculation based on the IMF IFS and EUROSTAT data.

ANNEX A.3 MODEL SPECIFICATION AND CHECKS

Table A.3.1 Misspecification Tests

Country	Lags	Normality	Autocorrelation		White Hetero	
		Doornik-Hansen	Portmanteau	p-val	no cross terms	cross terms
CZE	6	**0.0000**	0.22		**0.00**	**0.00**
CZE_DUM	6	**0.0001**	0.07		**0.00**	**0.01**
HUN	6	**0.0000**	0.19		0.59	0.20
POL	3	0.1139	0.30		0.14	0.08
SVK	1	**0.0000**	0.10		**0.00**	**0.00**
SVK_93	7	**0.0121**	0.09		**0.00**	**0.00**
SVN_96	6	**0.0023**	0.39		**0.05**	**0.01**
DEU	1	**0.0000**	0.21		0.81	0.79
ESP	1	0.1965	0.61		**0.01**	**0.02**
FRA	1	0.5493	0.26		0.83	0.90
GRC	3	**0.0000**	0.22		0.62	0.58
ITA	3	**0.0000**	0.13		**0.00**	**0.00**
PRT	1	0.0970	0.33		**0.01**	**0.02**
PRT_DUM	1	0.6609	0.19		**0.00**	**0.02**

Note: The lines CZE_DUM and PRT_DUM present results from estimating models specified with the dummy variable detected by structural break tests; lines SVN_93 and SVN_96 present results from estimating the models with the data spanning form 1993M4 to 2006M12 and from 1996M1 to 2006M12, respectively. The column marked 'Lags' includes number of lags chooses by the AIC criterion for the final estimation of VAR models. Columns 'Normality', Autocorrelation' and 'White Hetero' present p-values attached to estimated tests; figures in bold indicate that the null hypothesis cannot be rejected at the 5 per cent significance level.

Source: Author's estimates based on IMF IFS and EUROSTAT data

Table A.3.2 ARCH Test on Individual Residuals from VAR Equations

ARCH(12) LM Test	Estimator	Engel's LM Statistic	Probability	Engel's LM Statistic	Probability
		RER		NER	
Czech Republic	OLS	26.09	**0.01**	19.20	0.08
Czech Republic_DUM	OLS	8.72	0.73	6.11	0.91
Hungary	OLS	8.20	0.77	9.96	0.62
Poland	OLS	18.88	0.09	18.16	0.11
Slovak Rep.	OLS	17.32	0.14	30.36	**0.00**
Slovak Rep.	WLS	8.66	0.73	14.33	0.28
Slovenia	OLS	10.47	0.58	19.90	0.07
Slovenia	WLS	8.93	0.71	4.22	0.98
Germany	OLS	3.41	0.99	3.16	0.99
France	OLS	10.50	0.57	10.14	0.60
Italy	OLS	4.84	0.96	3.65	0.99
Italy	WLS	14.12	0.29	10.18	0.60
Greece	OLS	0.97	1.00	1.16	1.00
Portugal	OLS	31.53	**0.00**	34.44	**0.00**
Portugal_DUM	WLS	9.59	0.65	15.47	0.22
Spain	OLS	24.47	**0.02**	13.66	0.32
Spain	WLS	18.05	0.11	13.66	0.32

Note: The lines CZE_DUM and PRT_DUM present results from estimating models specified with the dummy variable detected by structural break tests;

Source: Author‘s estimates based on IMF IFS and EUROSTAT data

Table A.3.3 Bai et al., Structural Break Test

Country	Sample	Lags	Sup-W-15%	Exp-W-15%	Est Break	90% Conf. Int.
CZE	1996:10-2007:11	6	0.58	0.80	_1999:3	(1998:12, 1999:6)
HUN	1993:8-2007:11	6	1.00	1.00	_1997:5	(1996:9,1998:1)
POL	1996:3-2007:11	3	0.15	0.19	_2000:3	(2000:1,2000:5)
SVK	1997:3-2007:11	1	**0.02**	**0.01**	_2000:11	(1999:8, 2002:2)
SVN	1996:8-2006:12	6	0.48	0.57	_2002:3	(2001:11, 2002:7)
FRA	1993:3-1998:12	1	0.45	0.41	_1995:3	(1993:8,1996:10)
DEU	1993:3-1998:12	1	0.25	0.35	_1994:11	(1993:10,1995:12)
ESP	1993:3-1998:12	1	**0.01**	**0.01**	_1994:11	(1994:6,1995:4)
GRC	1993:5-2000:12	3	0.19	0.10	_1996:2	(1995:8,1996:8)
ITA	1993:5-1998:12	3	0.61	0.74	_1996:8	(1996:3,1997:1)
PRT	1993:3-1998:12	1	0.87	0.84	_1994:2	(X,1995:8)

Note: The highlighted p-values indicate the significance of the structural break at the 5 per cent level.

Source: Author‘s estimates based on IMF IFS and EUROSTAT data

Table A.3.4 Hansen Structural Break Test

TEST / EXCHANGE RATE	Lags	Breakpoint	Andrews			Bootstarp			Hetero-Corrected		
			SupF	ExpF	AveF	SupF	ExpF	AveF	SupF	ExpF	AveF
NER_CZE	6	29	**0.00**	**0.00**	0.26	**0.00**	**0.01**	0.29	**0.03**	**0.03**	0.22
RER_CZE	6	29	**0.00**	**0.00**	0.29	**0.00**	**0.00**	0.32	**0.04**	**0.04**	0.31
NER_HUN	6	151	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.00**	0.25	0.23	**0.00**
RER_HUN	6	113	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	0.12	0.10	**0.00**
NER_POL	3	101	0.13	0.10	0.07	0.16	0.14	0.06	0.22	0.17	**0.03**
RER_POL	3	101	0.20	0.17	0.12	0.25	0.22	0.11	0.28	0.23	0.06
NER_SVK	1	25	0.07	0.17	0.19	0.06	0.18	0.18	0.26	0.38	0.28
RER_SVK	1	25	0.47	0.85	0.94	0.48	0.89	0.94	0.55	0.86	0.92
NER_SVN	6	22	**0.00**	**0.00**	**0.02**	**0.00**	**0.01**	**0.02**	0.26	0.27	0.10
RER_SVN	6	66	**0.01**	**0.01**	**0.01**	**0.02**	**0.03**	**0.01**	0.10	0.11	**0.01**
NER_FRA	1	18	0.72	0.56	0.61	0.69	0.60	0.66	0.76	0.70	0.72
RER_FRA	1	17	0.91	0.72	0.75	0.87	0.75	0.77	0.85	0.75	0.75
NER_DEU	1	25	0.23	0.50	0.74	0.19	0.50	0.75	0.14	0.41	0.65
RER_DEU	1	25	0.13	0.31	0.63	0.13	0.34	0.67	0.10	0.30	0.56
NER_ESP	1	10	0.24	0.22	0.43	0.23	0.26	0.46	0.44	0.45	0.47
RER_ESP	1	10	0.29	0.31	0.57	0.24	0.36	0.61	0.47	0.51	0.58
NER_GRC	3	60	0.96	0.98	0.98	0.93	0.97	0.96	0.64	0.66	0.59
RER_GRC	3	15	1.00	1.00	1.00	1.00	1.00	1.00	0.89	0.73	0.61
NER_ITA	3	14	0.08	0.07	0.61	0.13	0.14	0.68	0.15	0.14	0.23
RER_ITA	3	14	0.09	0.06	0.60	0.15	0.14	0.69	0.12	0.10	0.24
NER_PRT	1	8	**0.00**	**0.00**	0.16	**0.00**	**0.00**	0.19	**0.03**	**0.04**	0.22
RER_PRT	1	8	**0.00**	**0.00**	0.31	**0.00**	**0.01**	0.31	**0.03**	**0.03**	0.35

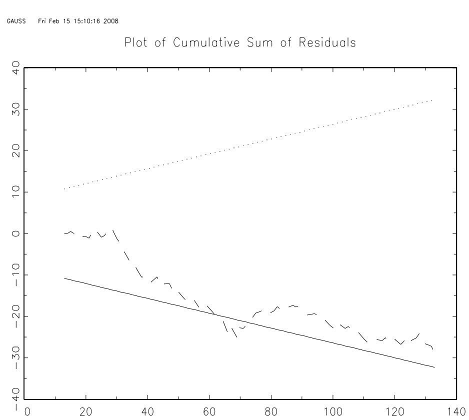
Note: Highlighted p-values indicate the significance of the structural break at the 5 per cent level.

Source: Author's estimates.

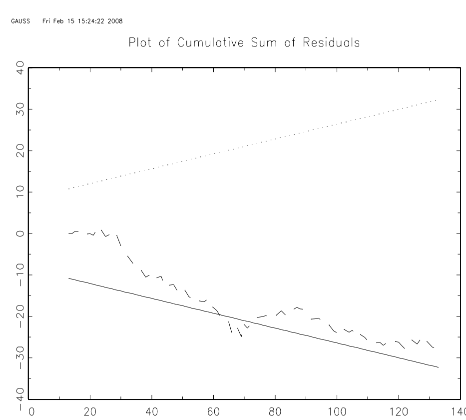
Figure A.3.1 CUSUM Sum and Sum of Squared Residuals Test

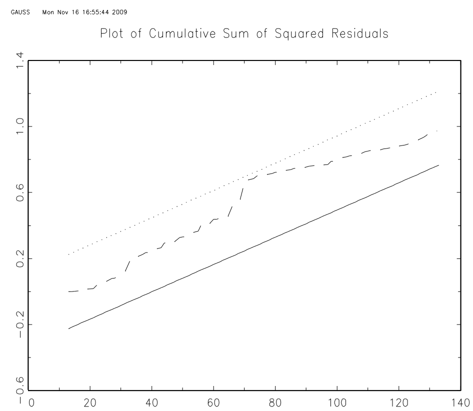
Czech Republic

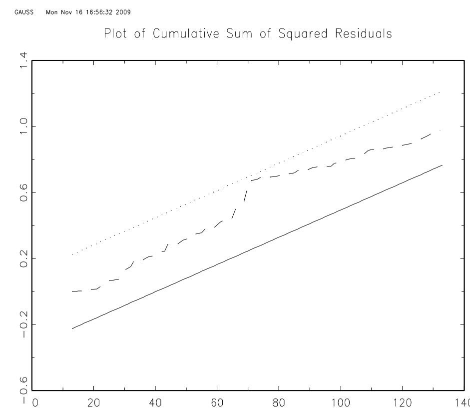
Real Exchange Rate



Nominal Exchange Rate

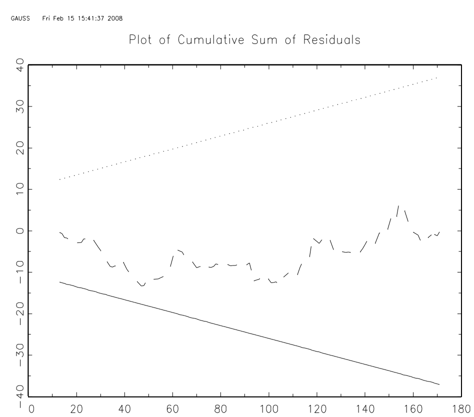


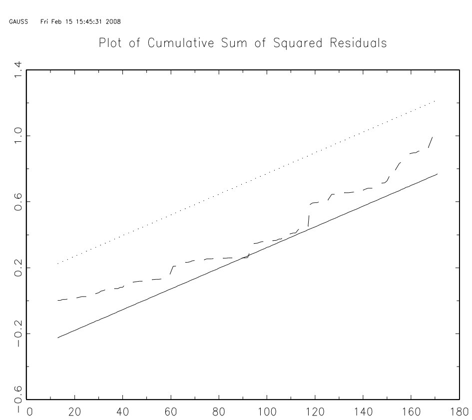




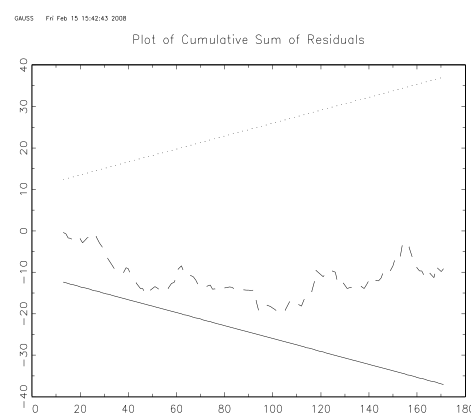
Hungary

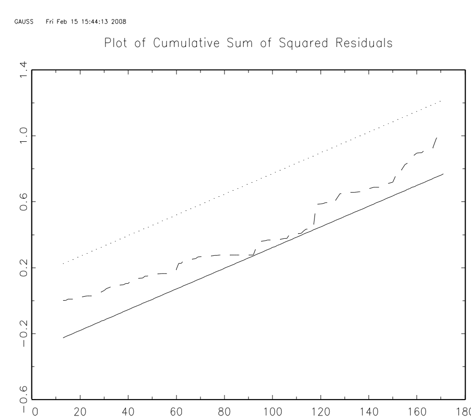
Real Exchange Rate





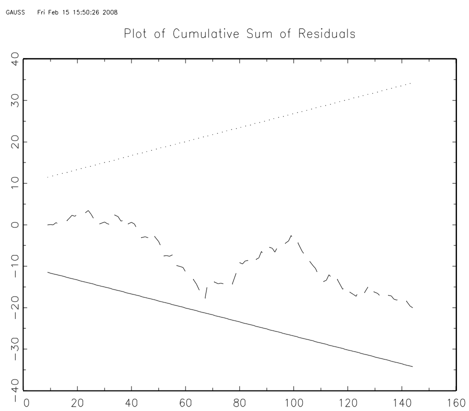
Nominal Exchange Rate



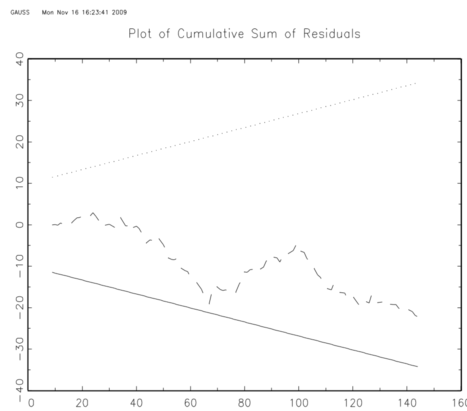


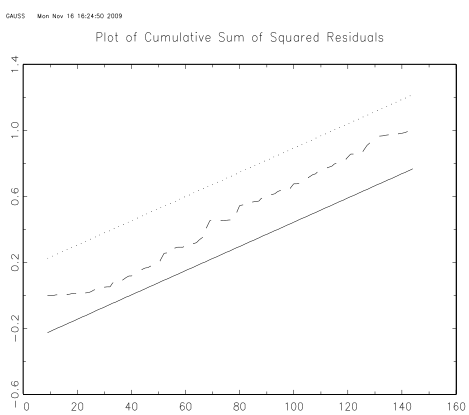
Poland

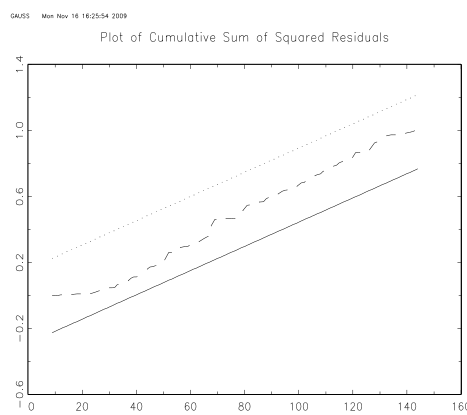
Real Exchange Rate



Nominal Exchange Rate

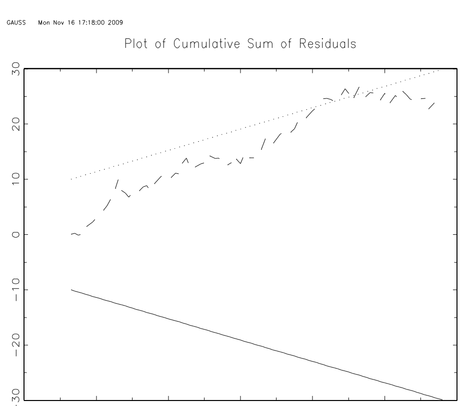




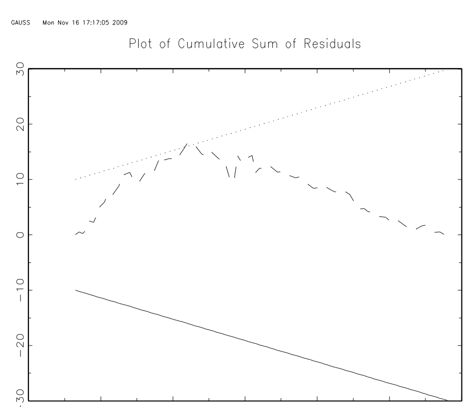


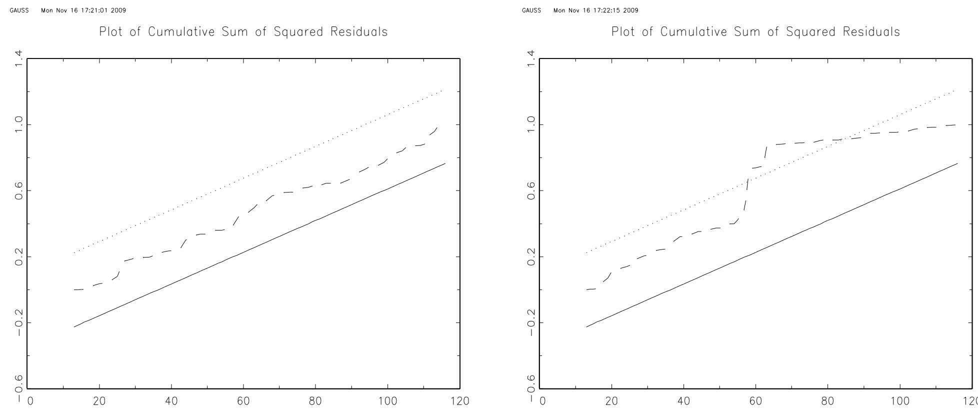
Slovenia

Real Exchange Rate



Nominal Exchange Rate

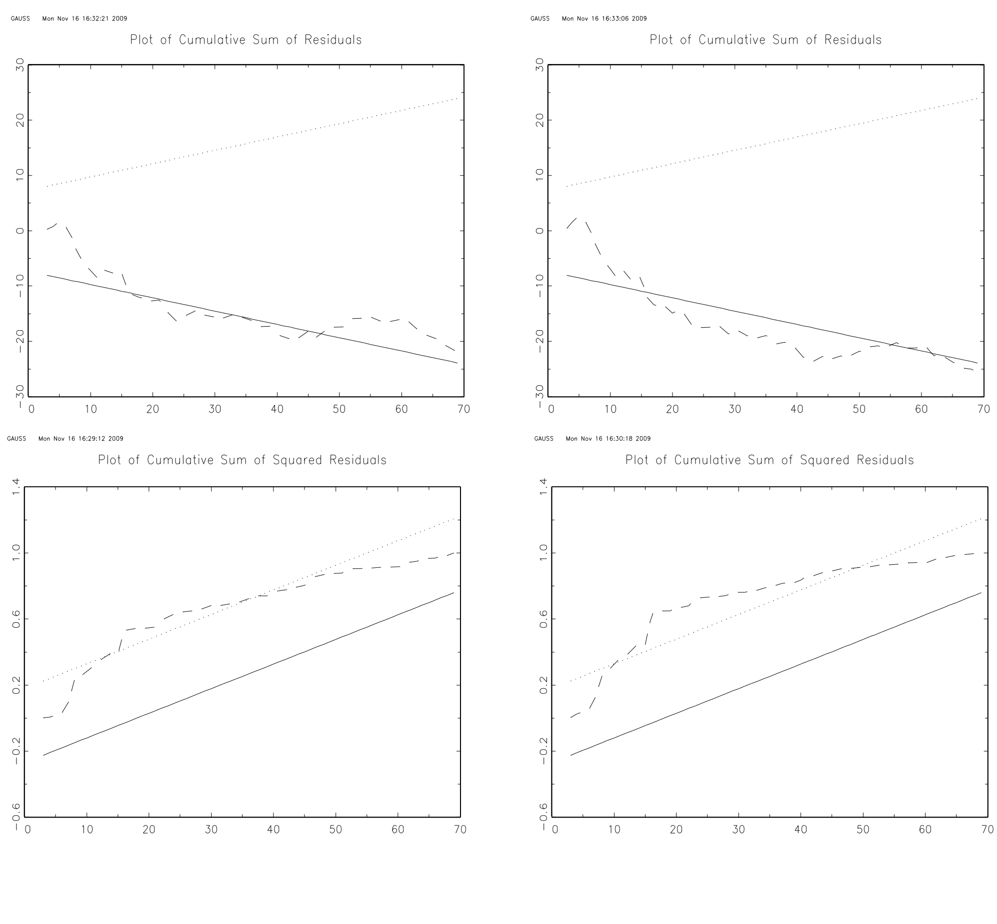




Portugal

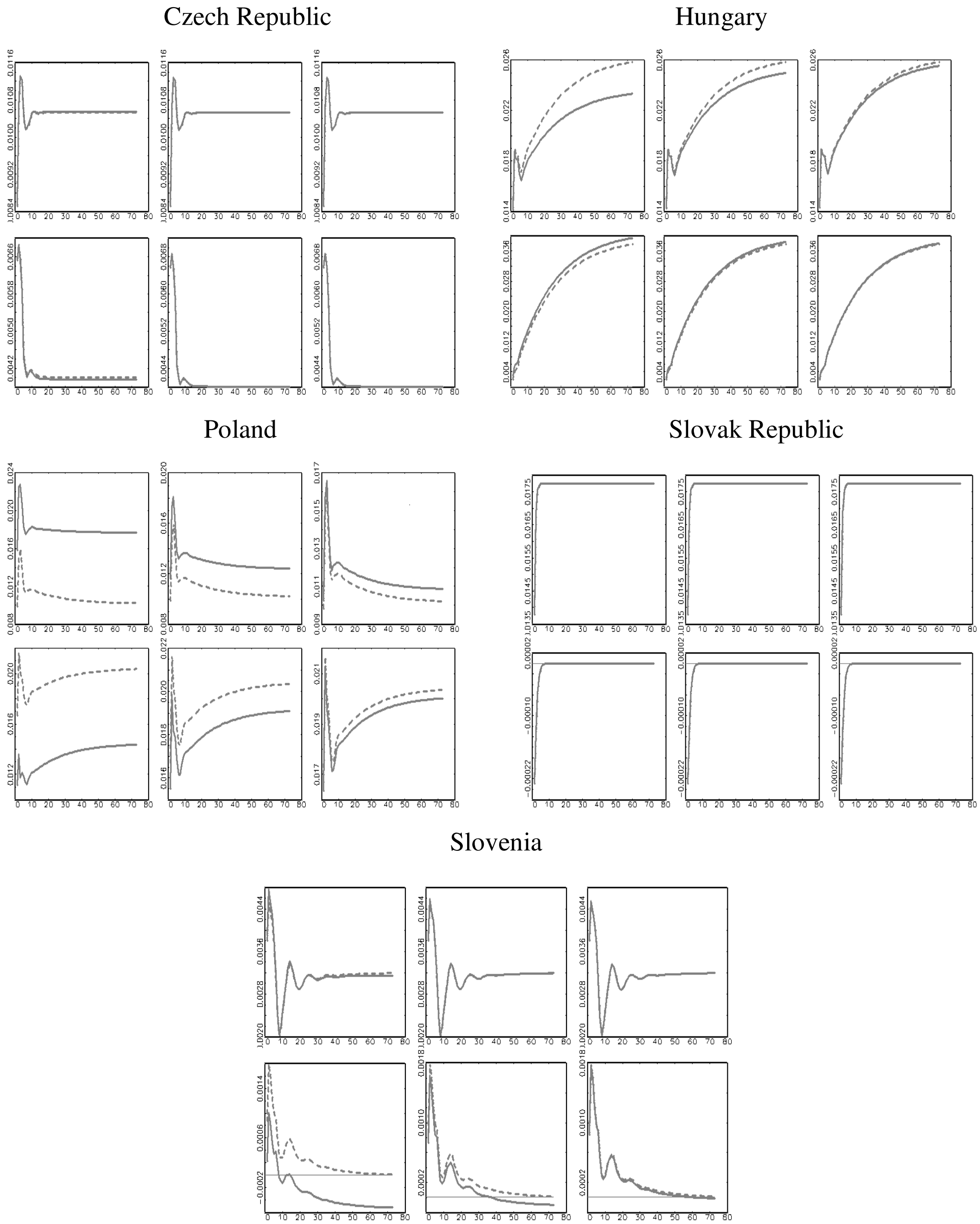
Real Exchange Rate

Nominal Exchange Rate



Source: Author's estimations based on IMF IFS and EUROSTAT data.

Figure A.3.2 Robustness Checks (NMSs)



Note: For each country, the first three panels in a first row present **nominal** exchange rates responses **to real shocks** with restrictions imposed on 1-year, 3-year and 5-year horizon, respectively. The second row is presented accordingly, but indicates **nominal** rates' responses **to nominal shocks**. Dashed lines are the lines with the identifying restrictions imposed at infinite horizons; solid lines, in respective panels, represent restrictions imposed on 1-year, 3-year and 5-year horizons.

Source: Author's estimations based on IMF IFS and EUROSTAT data.

ANNEX A.4 VARIANCE DECOMPOSITION AND IMPULSE RESPONSES (OMSS)

Table A.4.1 Variance Decomposition (OMSs)

Variable	RER				NER			
Variance Decomposition	RER shock		NER shock		RER shock		NER shock	
GERMANY								
1-month	99.8	94.1-100	0.2	0.0-5.9	96.6	86.0-100.0	3.4	0.0-14.0
3-month	100	98.0-100	0.0	0.0-2.0	97.5	92.6- 99.9	2.5	0.1-7.4
12-month	100	99.5-100	0.0	0.0-0.5	97.8	94.6-99.7	2.2	0.3-5.4
24-month	100	99.8-100	0.0	0.0-0.2	97.9	95.0- 99.7	2.1	0.3-5.0
60-month	100	99.9-100	0.0	0.0-0.1	97.9	95.1- 99.7	2.1	0.3-4.9
SPAIN								
1-month	87.2	14.0-100	12.8	0.0-86.0	67.4	0.0-94.6	32.6	5.3-100
3-month	89.9	21.8-100	10.1	0.0-78.2	73.6	9.1-99.6	26.4	0.4-90.9
12-month	97.2	74.0-100	2.8	0.0-26.0	84.8	34.2-99.1	15.2	0.9-65.8
24-month	98.7	85.5-100	1.3	0.0-14.5	87.9	44.5-99.9	12.1	0.1-55.5
60-month	99.5	89.5-100	0.5	0.0-10.5	89.8	45.3-100.0	10.2	0.0-54.7
FRANCE								
1-month	99.9	96.1-100	0.1	0.0-3.9	93.2	83.2-100	6.8	0.0-16.8
3-month	100	97.8-100	0.0	0.0-2.2	93.9	87.6-98.3	6.1	1.7-12.4
12-month	100	99.4-100	0.0	0.0-0.6	94.1	89.1-97.6	5.9	2.4-10.9
24-month	100	99.7-100	0.0	0.0-0.3	94.1	89.4-97.7	5.9	2.3-10.6
60-month	100	99.9-100	0.0	0.0-0.1	94.1	89.7-98.1	5.9	1.9-10.3
GREECE								
1-month	96.2	72.6-100	3.8	0.0-27.4	76.7	31.2-100	23.3	0.0-68.8
3-month	96.0	76.3-100	4.0	0.0-23.7	74.5	30.9-99.9	25.5	0.1-69.1
12-month	98.6	92.3-100	1.4	0.0-7.7	70.2	29.9-97.1	29.8	2.9-70.1
24-month	99.3	96.1-100	0.7	0.0-3.9	68.9	28.4-96.7	31.1	3.3-71.6
60-month	99.7	98.4-100	0.3	0.0-1.6	68.0	27.9-96.8	32.0	3.2-72.1
ITALY								
1-month	98.2	57.8-100	1.8	0.0-42.2	90.9	36.9-100	9.1	0.0-63.1
3-month	99.5	71.9-100	0.5	0.0-28.1	96.5	61.3-100	3.5	0.0-38.7
12-month	99.9	89.4-100	0.1	0.0-10.6	98.0	82.1-99.8	2.0	0.2-17.9
24-month	99.9	93.5-100	0.1	0.0-6.5	98.2	86.0-99.7	1.8	0.3-14.0
60-month	100	96.9-100	0.0	0.0-3.1	98.4	87.8-99.9	1.6	0.1-12.2
PORTUGAL								
1-month	99.3	76.0-100	0.7	0.0-24.0	74.9	32.2-100	25.1	0.0-67.8
3-month	99.8	83.9-100	0.2	0.0-16.1	71.4	32.3-99.1	28.6	0.9-67.7
12-month	99.9	95.2-100	0.1	0.0-4.8	69.1	30.7-95.0	30.9	5.0-69.3

24-month	100	97.5-100	0.0	0.0-2.5	68.7	27.1-94.4	31.3	5.6-72.9
60-month	100	99.0-100	0.0	0.0-1.0	68.4	26.6-95.9	31.6	4.1-73.5

Note: Column I and III reflect contributions of the real and nominal shocks, respectively, to the forecast variance error of the real exchange rate; columns V and VII contain the contributions of the same shocks to movements of the nominal exchange rate; the numbers in columns II, IV, VI and VIII represent the bootstrapped confidence intervals calculated for a particular percentage of variance decomposition.

Source: Author's estimations based on IMF IFS and EUROSTAT data.

CHAPTER 2

EXPLAINING REAL EXCHANGE RATE MOVEMENTS IN NEW MEMBER STATES OF THE EUROPEAN UNION – A BASIC SMALL OPEN ECONOMY MODEL

2.1 INTRODUCTION

The objective of this chapter is two-fold. First, within a SOE-DSGE IRBC model, to examine the extent to which real factors are responsible for the real exchange rate movements in the NMSs of the EU. A special emphasis is put on investigating the observed persistent appreciation in these countries since the early 1990s (see Figure A.1.1, Annex A.1 in Chapter 1), and in Poland in particular. Second, it seeks to generate within a DSGE framework the RER variability and persistence that is observed in the NMSs. A basic, one-sector, version of the model is presented here. An expanded, two-sector, version of the model is presented in Chapter 3.

Although there has been much discussion about real exchange rate movements in the NMSs in recent years (mainly due to their obligation to join the eurozone, and thus the requirement to meet Maastricht criteria and eventually abandon independent monetary and exchange rate policies), formal analyses usually consist of empirical studies, which utilize time-series or panel data econometric methods of the kind presented in Chapter 1[56]. To date very few DSGE models have been developed for the NMSs. Exceptions include Natalucci and Ravenna (2002, 2007), Laxton and Pesenti (2003), Masten (2008), Vilagi (2005), Lipińska (2008, 2008a) and Kolasa (2009). This is surprising given the recent trends in macroeconomic modelling, and the usefulness of adopting DSGE models for policy purposes. Also, given the existing data constraints in the new members of the EU, and the fact that limited data is required for DSGE modelling, this type of analysis should be even more attractive in the context of these economies. Of the DSGE-based studies for the NMSs that

[56] See also Egert (2002) or MacDonald and Wojcik (2004).

have been developed, none look explicitly at real exchange rate determinants, nor seek to match the magnitude of the real exchange rate volatility observed in the NMSs. For example, Natalucci and Ravenna (2002, 2007), examine the choice of exchange rate regime in the NMSs of the EU during the process of accession to the eurozone in the presence of the HBS effect. Laxton and Pesenti (2003), use their model to assess the effectiveness of Taylor rules and Inflation-Forecast-Based rules in stabilizing variability of output and inflation. Vilagi (2005) analyses the results of different productivity growth rates in traded and nontraded goods sectors on the timing of the entry into the eurozone and argues that the HBS effect can be consistent with the NOEM model, but only when firms price to the market. Masten (2008) looks at similar issues to Natalucci and Ravenna (2002, 2007) but unlike them uses a nonstationary DSGE model. Lipińska (2008, 2008a) investigates optimal monetary policy subject to Maastricht nominal convergence criteria. And finally, Kolasa (2009) presents an estimated DSGE model for Poland and the euro area and applies it to an assessment of the degree of heterogeneity between these two regions.

The goals set out in this paper are important for a number of reasons. First, the absence of a SOE model that explains real exchange rate determinants for a typical NMS is a gap in literature, given that such a model would be a useful policy tool to help analyse macroeconomic imbalances. Second, if progress is to be made in real convergence, it is important to detect sources of real asymmetries between NMSs and the eurozone (as argued in Chapter 1, real exchange rate volatility is a good indicator of real convergence, as its variability reflects underlying economic conditions). Moreover, to the extent that shocks that lead to real exchange rate movements in the NMSs that are obliged to adopt the euro are persistent and real in nature, they will also lead to inflation differentials between the NMSs and the eurozone. Third, Engel's (1999) empirical findings that in developed countries non-tradeables can be ignored in understanding RER movements, the weak evidence of the HBS effect in the NMSs (Egert (2002), Błaszkiewicz, et al. (2004), Mihaljek and Klau (2004), Wagner (2005)), and the hypothesis suggested in empirical work (Egert and Lommatzsch (2004), Lommatzsch and Tober (2004), Hanousek and Filer (2004) or Broeck and Slok (2006)) that the international deviations of the relative price of tradable goods led by quality changes may be responsible for the observed real exchange rate appreciation in the NMSs, all suggest that a one-sector model of RER determinants may also be suitable for the NMSs of the EU. Finally, identifying an economic model that can generate enough volatility as well as persistence of real exchange rates is not an easy task, even in the two-country symmetric DSGE set-up with nominal rigidities (see for example Chari et al. (2002), Søndergaard (2004)). The difficulty of explaining high and persistent RER volatility is regarded as 'puzzle' in the international macroeconomic literature. Indeed, also SOE-DSGE models calibrated to the NMSs have tended not to be able to generate RER volatility of the degree observed in the data (see Lipińska (2008, 2008a) or Natalucci and Ravenna (2002, 2007)). The exception is the model proposed by Laxton and Pesenti (2003), where modelled real exchange rate volatility is higher than that observed in the data. Therefore, it is of interest to see whether a standard international business cycle model of the kind proposed in this chapter can generate the volatile and persistent real exchange rates observed in the NMSs.

The findings of this chapter support the hypothesis that deviations from relative prices of tradable goods (i.e. quality and productivity shocks) are important sources of RER movements in the NMSs, represented by Poland (although a preference consumption shock also matters). It is further shown that, within the model, only a shock that improves the quality of domestically produced goods leads to RER appreciation. Positive changes to productivity bring about a depreciation of the real exchange rate. Surprisingly, the basic IRBC SOE-DSGE model performs reasonably well in delivering persistent real exchange rate. This result is robust to changes in the model parameters. However, the fit of the model in terms of the key moments of the data, when calibrated to the Polish economy, depends on the elasticity of substitution between home and foreign tradable goods, and its best matched when the value of this elasticity is very low. Therefore, the model needs further modification for the NMSs in order to be of use for policy purposes – the subject of Chapter 3.

The remainder of this chapter is organised as follows: Section 2 outlines the main features of the model. Section 3 sets out the theoretical model. Section 4 presents the parameterization of the model, and evaluates the model results and its ability to match the moments of the observed data. Section 5 concludes.

2.2 THE BASIC SOE MODEL – A NON- TECHNICAL SUMMARY

The model developed in this chapter is a simple one-sector small open economy model, in which it is assumed that the large economy is exogenous. The model includes home bias in consumption. The inclusion of home bias in the model of real exchange rate determinants is crucial for endogenous real exchange rate fluctuations to occur. With its presence, even if there are no barriers to trade, and if the LOOP holds continuously at the level of each individual good, equilibrium deviations from PPP are possible. Home bias depends on the relative size of the economy and its degree of openness as in Sutherland (2002) or de Paoli (2004). Due to this assumption it is possible to consider a limiting case in which the home economy is of zero size (see Section 2.3.1 and Annex B.2 for more details). Home bias also diminishes the expenditure-switching mechanism, adding to RER persistence and captures well documented quality changes in the NMSs of the EU (see below). Another feature of the model is the presence of an exogenous quality factor, which captures quality changes occurring in the NMSs, as does the home bias factor. However, unlike the home bias channel, which captures the shift towards higher quality products from the demand side, the exogenous quality factor captures changes occurring on the supply side. Prices and wages in the model are assumed to be flexible, but there are imperfections in the goods market (i.e. firms are monopolistically competitive). Small and large economies produce one type of good (but consume both), called home ‘H’ and foreign ‘F’, respectively[57]. Markets for internationally traded state contingent securities are complete.

The model differs in a number of ways from either existing DSGE models for the NMSs, and / or DSGE models of real exchange rates determinants for developed countries (see Chari et al. (2002), Devereux and Engel (2002) or Benigno and Thoenissen (2003)). The three principal areas of divergences of the proposed model from existing models are set out below.

[57] Domestic and foreign goods in the Foreign country are indexed H^* and F^*, respectively.

First, all existing DSGE models for the NMSs include nominal rigidities (i.e., they are open economy Keynesian monetary models) and analyse the role of monetary policy and / or money in economic fluctuations. The model in this chapter does not include monetary policy in explaining real exchange rate movements (and other business cycle statistics). This is for three reasons. The first reason is that the observed real exchange rate appreciation in the NMSs has been persistent despite lowering inflation rates in these countries, pointing to a possibly larger role of real (or supply-side) factors in real exchange rate movements in these countries – a hypothesis which was confirmed by the previous chapter's findings[58]. The second reason is that if real exchange rate movements are defined so as to measure real convergence in the NMSs, it is only of interest to detect how much of real exchange rate volatility can be explained by asymmetric real shocks (if the degree of real volatility is high, it points to a low degree of real convergence). The third reason is that, as shown in Søndergaard (2004), unless monetary policy shocks are assumed to be ten times more volatile than they really are, relying on the combination of nominal rigidities and monetary shocks does not help explain the observed real exchange rate volatility. In respect of the absence of monetary frictions, these are excluded in the model based on recent advances in the monetary theory and policy, which attributes a very limited role to money (usually this role is limited to a unit of account). As such, the model proposed in this paper may be viewed as a limiting case of a money-in-the-utility model, in which the weight of real balances in the utility function is arbitrarily close to zero (the so-called cashless economy as in Woodford (2003, Chapter 2)) [59].

Second, the model proposed in this chapter is a one-sector model in which all goods are traded – i.e., the model explains real exchange rate behaviour by the movements of the relative prices of domestic and foreign tradables – i.e., the external real exchange rate. The fact that the model includes the tradable sector only also

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[58] The role of nominal shocks in explaining real exchange rate volatility in the NMS turned out to be limited. In particular, in Poland which is characterized by the most flexible exchange rate regime, nominal shocks accounted for around 30 percent of the RER variability (see Chapter 1).

[59] It should be, however, stressed that the chapter does not argue the neutrality of money in economic fluctuations (coming from either monetary shocks or monetary policy). Nonetheless, as the primary concern of the chapter is to answer the question of the extent to which real factors contribute to the real exchange rate fluctuations, the proposed approach is appropriate for the purposes of this model.

distinguishes it from other DSGE models developed for the NMSs, which include both the tradable and nontradable sectors[60]. In this respect the model can be classified as belonging to the 'Engel' school. Examples of such models for developed countries can be found in Chari, et al. (2002), Devereux and Engel (2002), Søndergaard (2004) among others. The hypothesis that a one-sector model can also be suitable for the NMSs of the EU is supported by recent empirical studies (Egert and Lommatzsch (2004), Lommatzsch and Tober (2004), Hanousek and Filer (2004) or Broeck and Slok (2006)). In particular, these studies argue that a quality factor may be an important determinant of real exchange rate movements in Poland. For example, Egert and Lommatzsch (2004) and Broeck and Slok (2006), using panel data techniques, find that quality improvements of tradable goods in catching-up economies are a source of tradable real exchange rate appreciation. Lommatzsch and Tober (2004) bring support to the hypothesis that productivity increases in industry in the Czech Republic, Hungary and Poland can be regarded as one source of the observed PPI-based real appreciation of the accession countries' currencies. Because the productivity gains experienced during economic catch-up occur as higher-quality goods are produced (implying increased export capacity and import substitution), they conclude that to some extent real appreciation can therefore be viewed as an equilibrium phenomenon. Similarly, Hanousek and Filer (2004) show that the quality bias in the CPI index in the Czech Republic led to the overstatement of inflation by around 5 percentage points a year in the first decade of economic transformation. Section 2.4.1 of this chapter also shows that it is not an implausible assumption that quality changes are an important element of RER appreciation in Poland, reflecting the fact that recent improvements in the Polish terms-of-trade have also been associated with increases in export unit values, which in turn have been accompanied by increases in quantities exported.

Third, the SOE model put forward in this chapter does not include local-currency-pricing (LCP), which is usually present in DSGE models that attempt to address the issue of the volatility and persistence of real exchange rates. For example, Chari et al. (2002) in their attempt to resolve the problem propose a complete market

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[60] As mentioned, in general there are no DSGE models of real exchange rate determinants for the NMSs of the EU. Nonetheless, all other DSGE models developed for the NMSs include a nontradable sector.

model with sticky prices, LCP, and without a nontradable good (see also Devereux and Engel (2002)). They find that a high degree of real exchange rate volatility can only be achieved with monetary shocks. However, even if the observed Polish real exchange rate is volatile and persistent (see previous chapter), this finding is not satisfactory. This is because, as stressed above, the majority of the real exchange rate movements in Poland (and other the NMSs) are real in nature. Moreover, integrating the LCP component into the DSGE model would not be an appropriate strategy as the real exchange rate pass-through in Poland is higher than that of the US, although not complete (see Goldberg and Campa (2006)). Instead, in the absence of nominal rigidities in the model, to slow down the expenditure switching mechanism, home bias in consumption is relied on. In the presence of home bias, the perceived similarity between Home and Foreign tradable goods is lowered and thus the degree of real exchange rate pass-through is diminished.

Finally, unlike the majority of existing models for the NMSs, the model in this chapter is calibrated to the Polish economy[61].

2.3 THE SOE / DSGE / IRBC MODEL – TECHNICAL DETAILS

In the model there is continuum of infinitely lived agents of unit mass, $s \in [0,n]$ belonging to the home country ('Home'), and $s^* \in (n,1]$ belonging to the large economy (represented by the eurozone and called 'Foreign'), where n is the size of the home country. It is assumed that n→0, so only the home economy is considered (i.e., the SOE case). There is no migration. Households consume all varieties of home and foreign goods and have access to international markets where they can trade a state-contingent real bond. Households supply labour services to firms as well as rent out the capital they own. The firms in both economies are distributed along the same intervals as households, i.e. domestic firms are indexed by $f \in [0,n]$,

[61] At the time of writing none of the DSGE models developed for the NMSs were calibrated to Poland. As of now, the most recent version of Lipińska's (2008a) paper and the work of Kolasa (2008) focus on Poland. Lipińska investigates optimal monetary policy subject to Maastricht nominal convergence criteria and uses calibration techniques. Kolasa presents an estimated DSGE model for Poland and the euro area and applies it to assess the degree of heterogeneity between these two regions. Otherwise, all above mentioned papers try to match the moments for the Czech Republic.

foreign firms by $f^* \in (n,1]$. Each firm at home and abroad produces one of the varieties of the domestic and foreign goods, respectively, so that differentiated goods (varieties) in two countries are also indexed by f and f^*.

2.3.1 Households

The utility function of a representative household s is separable in arguments and given by:

$$(2.1) \qquad U_t^s = E_t \left\{ \sum_{t_0=t}^{\infty} \beta^{t_0-t} \left[U\left(C_{t_0}^s, (1-N_{t_0}^s) \right) \right] \right\}$$

where E_t - expectations conditional on the information set at date t, β^{t_0-t} is the intertemporal discount factor and $0<\beta<1$. Household s gets his utility $U_t^s(\bullet)$ from the consumption of the composite good $C_{t_0}^s$ discounted for the disutility of supplying labour $N_{t_0}^s$.

The composite good C_t^s consumed by household s is aggregated from home H and foreign F goods using the CES aggregator:

$$(2.2) \qquad C_t^s = \left[\lambda^{\frac{1}{\phi}} C_{H,t}^{s\ \frac{\phi-1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}} C_{F,t}^{s\ \frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}$$

where $0<\phi<1$ and $\phi>1$ is the elasticity of substitution between home and foreign goods[62], $\lambda \in [0,1]$ represents the degree of home bias in the small open economy[63].

[62] ϕ is restricted to be greater than zero (and different than one) for home and foreign goods to be substitutes. The larger the ϕ, the more substitutable H and F goods are. The Cobb-Douglas case (elasticity equal one) is not considered in this paper as it does not allow for the discussion about substitutability of goods.

[63] Note, subscripts H and F refer to domestic and foreign goods consumed in the Home country. Subscripts H* and F* refer to domestic and foreign goods consumed in the Foreign country (i.e., F* is a foreign consumption good that is produced and consumed by foreigners).

Since the composite good aggregator is the zero-profit agent, he sells the composite good C_t^s at the price P_t, which also corresponds to the country consumer price index[64]:

$$P_t \equiv \left[\lambda P_{H,t}{}^{1-\phi} + (1-\lambda) P_{F,t}{}^{1-\phi} \right]^{\frac{1}{1-\phi}} \tag{2.3}$$

where $P_{H,t}$ and $P_{F,t}$ are the prices of a composite Home and Foreign consumption good, respectively.

Following Sutherland (2002) and de Paoli (2004), home bias λ is assumed to be a function of the relative size of the home economy with respect to the rest of the world (eurozone) and its degree of openness ω such that $1-\lambda = (1-n)*\omega$. Since n→0, we have $1-\omega = \lambda$[65]. This means the less open the economy, the larger the home bias[66]. Also, in the small open economy case, the presence of home bias breaks the PPP between countries (unless the elasticity of substitution between domestic and foreign goods in both countries differs, without home bias, PPP would hold),

Sectoral consumption goods H and F are derived by aggregation across individual varieties. Home and Foreign produced final goods, $C_{H,t}^s$ and $C_{F,t}^s$, are composites of individual brands $C_{H,t}^s(f)$ and $C_{F,t}^s(f)$, i.e., the zero-profit agent buys individual brands $C_{H,t}^s(f)$ and $C_{F,t}^s(f)$ at the price $P_{H,t}(f)$ and $P_{F,t}(f)$, respectively, bundles them into the aggregate goods $C_{H,t}^s$ and $C_{F,t}^s$ according to the following Dixit-Stiglitz indices[67]:

$$C_{H,t}^s \equiv \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma_H}} \int_0^n C_{H,t}^s(f)^{\frac{\sigma_H - 1}{\sigma_H}} df \right]^{\frac{\sigma_H}{\sigma_H - 1}} \tag{2.4}$$

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[64] See Annex B.1 for derivations.
[65] See Annex B.2 for derivations.
[66] The intuition is that smaller economies, because they cannot sustain themselves, tend to be more open.
[67] It can be proved that in equation (2.4) $\lim_{n \to 0} C_{H,t} = e^{-\infty} = 0$ for $|\sigma_H| > 1$.

$$(2.5) \qquad C^s_{F,t} \equiv \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\sigma_F}} \int_n^1 C^s_{F,t}(f)^{\frac{\sigma_F - 1}{\sigma_F}} df \right]^{\frac{\sigma_F}{\sigma_F - 1}}$$

where $\sigma_H, \sigma_F > 1$ represents the elasticity of substitution between differentiated goods (brands) in the home and foreign sectors and is also the price elasticity of demand faced by each producer[68].

Then, the bundler sells them to households at the following sectoral price:

$$(2.6) \qquad P_{H,t} \equiv \left[\left(\frac{1}{n} \right) \int_0^n P_{H,t}(f)^{1-\sigma_H} df \right]^{\frac{1}{1-\sigma_H}}$$

$$(2.7) \qquad P_{F,t} \equiv \left[\left(\frac{1}{n-1} \right) \int_n^1 P_{F,t}(f)^{1-\sigma_F} df \right]^{\frac{1}{1-\sigma_F}}$$

Individual households also consume investment goods. It is assumed that the composite investment I^s_t is produced by the same final goods aggregator who is producing the composite consumption good, C^s_t. Specifically, it is assumed that the investment good is produced using a composite of domestic and foreign goods using the following CES index:

$$(2.8) \qquad I^s_t = \left[(1-\omega)^{\frac{1}{\phi}} I^s_{H,t}{}^{\frac{\phi-1}{\phi}} + (\omega)^{\frac{1}{\phi}} I^s_{F,t}{}^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}$$

where again

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[68]The elasticity of substitution between different varieties of the consumption good is set to be greater then 1 to capture the idea that consumption varieties are good substitutes for each other (i.e., with this elasticity equal to 0, different varieties would be perfect complements to each other, the interior solution would not exist. If the elasticity was equal 1 then different varieties would be perfect substitutes to each other, which undermines the assumption about monopolistic competition).

(2.9) $$I_{H,t}^{s} \equiv \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma_H}} \int_{0}^{n} I_{H,t}^{s}(f)^{\frac{\sigma_H - 1}{\sigma_H}} df \right]^{\frac{\sigma_H}{\sigma_H - 1}}$$

(2.10) $$I_{F,t}^{s} \equiv \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\sigma_F}} \int_{n}^{1} I_{F,t}^{s}(f)^{\frac{\sigma_F - 1}{\sigma_F}} df \right]^{\frac{\sigma_F}{\sigma_F - 1}}$$

The elasticity of substitution between H and F goods, ϕ, as well as price elasticities of demand, σ_H, are the same as in the corresponding consumption indices. Given the assumption about identical aggregation of consumption and investment goods, the price indices for consumption and investment goods are also identical.

Individual consumption and investment demand functions for the representative consumer can be obtained from the optimal allocation of expenditure across the H and F goods[69]:

(2.11) $$C_{H,t}^{s}(f) = \frac{1}{n} \lambda \left(\frac{P_{H,t}(f)}{P_{H,t}} \right)^{-\sigma_H} \left(\frac{P_{H,t}}{P_t} \right)^{-\phi} C_t^{s}$$

(2.12) $$I_{H,t}^{s}(f) = \frac{1}{n} \lambda \left(\frac{P_{H,t}(f)}{P_{H,t}} \right)^{-\sigma_H} \left(\frac{P_{H,t}}{P_t} \right)^{-\phi} I_t^{s}$$

(2.13) $$C_{F,t}^{s}(f) = \frac{1}{1-n} (1-\lambda) \left(\frac{P_{F,t}(f)}{P_{F,t}} \right)^{-\sigma_F} \left(\frac{P_{F,t}}{P_t} \right)^{-\phi} C_t^{s}$$

(2.14) $$I_{F,t}^{s}(f) = \frac{1}{1-n} (1-\lambda) \left(\frac{P_{F,t}(f)}{P_{F,t}} \right)^{-\sigma_F} \left(\frac{P_{F,t}}{P_t} \right)^{-\phi} I_t^{s}$$

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[69] See Annex B.3 for detailed derivations of consumption demand functions. The functions for investment can be derived analogously.

Households Capital Accumulation

Every firm rents capital services at the going rental rate r_t^K from households. Households can increase the supply of capital services by accumulating more physical capital. Capital K_{t-1}^s is pre-determined at the beginning of each period (i.e., at time *t*).

The stock of capital increases in accordance with the following law of motion (see, for example, Chari et al. (2002)):

$$K_t^s = (1-\delta)K_{t-1}^s + I_t^s - \frac{\nu}{2}\left(\frac{I_t^s}{K_{t-1}^s} - \delta\right)^2 K_{t-1}^s \tag{2.15}$$

where ν is the adjustment cost in changing the capital stock employed by each intermediate good producer, and δ is the depreciation rate (common for both sectors).

The quadratic function assumes that the adjustment is slow[70]. Because K_t^s is the end of period stock, the capital that will be available for use in period t+1. Note that because investment good I_t is an aggregate of H and F goods, foreign goods contribute to capital accumulation in the small open economy.

Resource constraint

There is a complete set of state contingent assets that can be traded across countries, i.e., international asset markets are complete. It is assumed that all households within the country have the same initial wealth, and share earned profits in equal

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[70] Here, capital adjustment costs are given by $\frac{\nu}{2}\left(\frac{I_t^s}{K_{t-1}^s} - \delta\right)^2 K_{t-1}^s$ and are a strictly convex function of investment (i.e., any change in the capital stock away from its steady state value δI is costly). Moreover, both the level and the slope of this function vanish at the steady-state so that the steady-state value of investment equals to $I_t = \delta K_{t-1}$.

proportion. This means that within the country all households face the same budget constraint (in units of domestic consumption good) [71]:

$$(2.16)\quad E_t\left(\Xi_{t,t+1}Q_{t+1}B_{t+1}\right)+C_t+I_t\le Q_tB_t+w_tN_t+r_t^KK_{t-1}+\frac{\int_0^n\Pi_t(f)dn}{n}+TR_t$$

Household expenditures (in units of domestic consumption good) are on the left hand side of (2.16). $E_t\left(\Xi_{t,t+1}Q_{t+1}B_{t+1}\right)$ is the price of a portfolio of state-contingent real bonds traded internationally, denominated in foreign consumption units and expressed in home consumption units (therefore Q_t is a real exchange rate expressed as a unit of foreign consumption good per unit of domestic consumption good), $\Xi_{t,t+1}$ is the stochastic discount factor for one period ahead payoff (contingent claim) B_{t+1}. I_t stands for households' investment decisions, C_t expresses consumption expenditure. Household income sources (also denominated in units of domestic consumption good) are the right hand side of (2.16). Q_tB_t is the payoff of the portfolio in period t, w_tN_t expresses household's labour income from working in the domestic sector, TR_t stands for real lump-sum government transfers, Π_t is a real profit of a domestic firm *f* received by the household in period *t*. Finally, $r_t^KK_{t-1}$ depict household's rental income from renting capital services to goods-producing firms (notice: $r_t^K=R_t^K/P_t, w_t=W_t/P_t$). Consumers face a no-Ponzi game restriction[72]. Transversality conditions apply[73]. The short term net real interest rate r_t is the price of the portfolio which delivers one unit of the domestic good in each contingency that occurs next period (i.e., in every state of period t+1):

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[71] Therefore, in what follows, the superscript s was suppressed.

[72] No-Ponzi condition is an inequality constraint bounding debt or net worth from below (i.e., households cannot role over debt forever (i.e., consume more than lifetime income)). It is perceived by agents as set externally.

[73] The TVC is a condition for optimization playing the role of ruling out solutions in which wealth grows rapidly forever but is never used to provide consumption or dividends. This essentially means that no-Ponzi restriction holds with equality.

(2.17) $$\frac{1}{(1+r_t)} = E\left(\Xi_{t,t+t_0+1}\right)$$

In order to maximize utility, households choose a sequence of $\left\{C_t, I_t, K_t, B_t, N_t\right\}_{t=0}^{t=\infty}$ for all t=0…..∞, subject to the budget constraint and an equation describing capital accumulation, i.e. they solve the following maximization problem[74]:

$$\max_{C_t, I_t, B_t, N_t, K_t} E_t\left\{\sum_{t_0=t}^{\infty}\beta^{t_0-t}\left[U\left(C_{t_0},(1-N_{t_0})\right)\right]\right\}+$$

$$\beta^{t_0}\lambda_{t+t_0}^{M}\left(\begin{array}{l} Q_{t+t_0}B_{t+t_0}+w_{t+t_0}N_{t+t_0}+r_{t+t_0}^{K}K_{t+t_0-1}-\dfrac{\int_0^n \Pi_{H,t+t_0}(i)di}{n}+TR_{t+t_0} \\ -E_t\left(\Xi_{t+t_0+1}Q_{t+t_0+1}B_{t+t_0+1}\right)-C_{t+t_0}-I_{t+t_0} \end{array}\right)+$$

$$+\beta^{t_0}\xi_{t+t_0}^{M}\left((1-\delta)K_{t+t_0-1}+I_{t+t_0}-\frac{\nu}{2}\left(\frac{I_{t+t_0}}{K_{t+t_0-1}}-\delta\right)^2 K_{t+t_0-1}\right)$$

where λ_t^M is the marginal utility of the final home consumption, and ξ_t^M is the multiplier associated with the capital constraint of the household.

Since all households face the same stochastic discount factor and start from the same level of wealth, their $\lambda_t^M, \xi_t^M, C_t$ and I_t will be the same in equilibrium. The first-order conditions with respect to the maximization objects above are given by:

(2.18) $$C_t : U_C(C_t, N_t) = \lambda_t^M$$

(2.19) $$N_t : U_N(C_t, N_t) + \lambda_t^M w_t = 0$$

(2.20) $$B_{t+1} : \frac{1}{1+r_t} = \beta E_t\left[\frac{Q_{t+1}\lambda_{t+1}^M}{Q_t\lambda_t^M}\right]$$

(2.21) $$I_t : \lambda_t^M = \xi_t^M - \xi_t^M \nu\left(\frac{I_t}{K_{t-1}}-\delta\right)$$

[74] Notice that profits are zero in equilibrium.

(2.22)

$$K_t : \xi_t^M = \beta E_t \lambda_{t+1}^M r_t^K$$
$$-\beta E_t \xi_{t+1}^M \left((1-\delta) - \frac{v}{2}\left(\frac{I_{t+1}}{K_t} - \delta\right)^2 + v\left(\frac{I_{t+1}}{K_t} - \delta\right)\left(\frac{I_{t+1}}{K_t}\right) \right)$$

2.3.2 Risk sharing condition

Recall that the internationally traded bond is expressed in the foreign consumption units in both countries. This implies that the first order condition for bond holdings for the foreign economy is:

(2.23)
$$\beta \mathrm{E}_t \left[\frac{\lambda_{t+1}^{M*}}{\lambda_t^{M*}} \right] = \frac{1}{1+r_t^*}$$

Because the model assumes complete markets, all households in the small/domestic and large/foreign economy face the same contingent claims prices and probabilities:

(2.24)
$$\beta \mathrm{E}_t \left[\frac{Q_{t+1}\lambda_{t+1}^M}{Q_t \lambda_t^M} \right] = \frac{1}{1+r_t^*} = \beta \mathrm{E}_t \left[\frac{\lambda_{t+1}^{M*}}{\lambda_t^{M*}} \right]$$

Using foreign and domestic first-order conditions for consumption, this can be re-written as:

(2.25)
$$\frac{U_C(C_{t+1}, N_{t+1})Q_{t+1}}{U_C(C_t, N_t)Q_t} = \frac{1}{1+r_t^*} = \frac{U_C^* \ (C_{t+1}^*, N_{t+1}^*)}{U_C^* \ (C_t^*, N_t^*)}$$

Now, iterating backwards:

(2.26)
$$\frac{U_C(C_t, N_t)Q_t}{U_C(C_0, N_0)Q_0} = \frac{U_C^* \ (C_t^*, N_t^*)}{U_C^* \ (C_0^*, N_0^*)}$$

and rearranging:

(2.27) $$\frac{U_C^*\ (C_t^*, N_t^*)}{U_C(C_t, N_t)Q_t} = \frac{U_C^*\ (C_0^*, N_0^*)}{Q_0 U_C(C_0, N_0)}$$

one gets:

(2.28)

$$\frac{U_C^*\ (C_t^*, N_t^*)}{U_C(C_t, N_t)} = \Gamma Q_t$$

where $\Gamma = \frac{U_C^*\ (C_0^*, N_0^*)}{Q_0 U_C(C_0, N_0)}$ and is determined by the initial consumption conditions (net foreign assets) at home and abroad.

Assuming that household preferences are additively separable, their objective is to maximise the following utility function[75]:

(2.29) $$U(C_t, N_t) = \max E_t \left\{ \sum_{t_0 - t}^{\infty} \beta^{t_0 - t} \left[\Upsilon_{C,t_0}^{\rho} \frac{C_{t_0}^{1-\rho}}{1-\rho} - \Upsilon_{N,t_0} \frac{\eta_0 N_{t_0}^{\ 1+1/\eta}}{1+1/\eta} \right] \right\},$$

where ρ is the coefficient of relative risk-aversion (and $1/\rho$ is the intertemporal elasticity of substitution for consumption), η is the Frisch intertemporal elasticity of substitution, η_0 is the parameter determining the level of labour supply, Υ_{C,t_0} is a consumption preference shock. Υ_{N,t_0} is a shock to labour disutility.

With the above utility function, the expression for the real exchange rate in the complete market set-up takes the following form:

[75] Chari et al. (2002) stresses that a utility function that is separable in consumption and leisure is necessary to achieve high exchange rate volatility. This is because following a shock, a non-separable utility function gives small changes in marginal utility of consumption, as changes in leisure offset some of the changes in consumption.

$$Q_t = \Gamma\left(\frac{C_t}{C_t^*}\right)^{\rho} \qquad (2.30)$$

Assuming - without loss of generality - symmetric initial conditions, $\Gamma = 1$, it follows that consumption based real exchange rate is proportional to the ratio of marginal utilities of wealth across countries (notice: if the PPP condition was satisfied, the level of consumption would equalize across countries at all times $C_t = C_t^*$. Thus, consumption will differ across the two countries only to the extent that there are changes in the real exchange rate.

While this condition simplifies aggregation, it directly links relative consumption to the real exchange rate. This implies the unitary (or almost unitary) correlation between the two, something not observed in the data. Moreover, it does not allow for wealth effects which maybe significant.

2.3.3 Firms (supply side)

Firms (indexed by $f \in [0, n)$) in the domestic sector behave as monopolistic competitors (i.e., each firm is large in its market but small with respect to the whole economy) but face flexible prices. Each firm at the beginning of period (time t) rents capital K_{t-1} from domestic households at the rate r_t^K, hires labour at the rate w_t and produces one of the brands (varieties) of home intermediate goods using domestic capital and labour (labour is mobile between sectors, but immobile internationally).

Each monopolist chooses its price and commits to satisfying demand at this price. His objective is to maximize profits (minimize costs). Firms take the wage rate, aggregate price indices and the world aggregates as given. Likewise, each monopolistic firm f in Home produces a homogenous good according to the following standard Cobb-Douglas production function:

(2.31) $$Y_{H,t}(f) = Y_{H,t} = \chi_t^{\iota-1} A_t (K_{t-1})^{\alpha} (N_t)^{1-\alpha}$$

where χ_t and A_t and are country specific quality and productivity shocks, respectively.

Following Hobijn (2002) and Dury and Oomen (2007), a parameter ι is introduced. This parameter determines the impact of quality changes on the marginal cost of the firm. Note that if $\iota - 1 < 0$ quality improvements increase the marginal costs of production (differently to the productivity improvements).

Optimal price setting

As discussed, it is assumed that firms in the domestic sectors face flexible prices although they behave as monopolists in selling their products. In setting their prices, they face the following optimal pricing problem.

Profit maximization

A domestic firm f chooses a price $P_{H,t}(f)$ for the domestic market and $P_{H,t}^{*}(f)$ for the foreign market (both expressed in the local currency). The earned profits (expressed in aggregate consumption) depend on the amount sold at those markets, the marginal cost of the firm and the revenue tax τ in the domestic sector:

$$\max_{P_{H,t}(f),\, P_{H,t}^{*}(f)} \left[\left((1-\tau)\frac{P_{H,t}(f)}{P_t} - \frac{MC_{H,t}}{P_t} \right) Y_{H,t}^{d}(f) + \left(Q_t (1-\tau)\frac{P_{H,t}^{*}(f)}{P_t^{*}} - \frac{MC_{H,t}}{P_t} \right) Y_{H,t}^{*d}(f) \right]$$

(2.32) $$\text{s.t: } Y_{H,t}^{d}(f) = \left(\frac{P_{H,t}(f)}{P_{H,t}} \right)^{-\sigma_H} Y_{H,t}^{d}$$

$$Y_{H,t}^{*d}(f) = \left(\frac{P_{H,t}^{*}(f)}{P_{H,t}^{*}} \right)^{-\sigma_H} Y_{H,t}^{*d}$$

where $Y_H^d(f)\,(Y_H^{d*}(f))$ is a total individual home (foreign) demand for variety f in the domestic sector, and $Y_{H,t}^d$ $(Y_{H,t}^{d*})$ is an aggregate home (foreign) demand for a home good (consumption and investment).

Note further that since households supply a homogenous type of labour and capital (i.e., firms share common factor prices w_t and r_t^K), and since they face the same productivity shocks, the real marginal cost is common across firms. Maximization of this function yields the following profit-maximizing prices[76]:

$$\text{(2.33)} \qquad \frac{P_{H,t}(f)}{P_t} = \frac{P_{H,t}}{P_t} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau}\frac{MC_{H,t}}{P_t} = mk_H mc_{H,t}$$

$$\text{(2.34)} \qquad \frac{P_{H,t}^*(f)}{P^*_t} = \frac{P_{H,t}^*}{P^*_t} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau}\left(\frac{MC_{H,t}}{P_t}\frac{1}{Q_t}\right) = \frac{mk_H mc_{H,t}}{Q_t}$$

where $mk_H = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau}$ (domestic mark-up), $mc_{H,t} = \frac{MC_{H,t}}{P_t}$ (real marginal cost).

From the cost minimization problem of the firm (i.e. the producer chooses the amount of capital and labour in order to minimise the cost of production subject to the given production function):

$$\text{(2.35)} \qquad \begin{aligned} &\min_{Y_t} R_t^K K_t + W_t N_t \\ &\text{s.t. } Y_{H,t} = \chi^{L-1} A_t (K_{t-1})^{\alpha} \; (N_t)^{1-\alpha} \end{aligned}$$

the following ratio is obtained:

$$\text{(2.36)} \qquad \frac{R_t^H K_{t-1}}{\alpha} = \frac{W_t N_t}{1-\alpha}$$

[76] Given that each domestic firm faces the same marginal cost as well as flexible prices, prices of goods are the same across firms. This essentially means that $P_{H,t}(f) = P_{H,t}$.

And finally the nominal marginal cost is derived: (see Annex B.3 for details):

$$MC_{H,t} = \frac{\delta TC}{\delta Y_{H,t}(f)} = \frac{\left(R_t^K\right)^{\alpha} W_t^{1-\alpha}}{\chi_t^{t-1} A_t} \left\{ \frac{1}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \right\} \tag{2.37}$$

2.3.4 Fiscal policy

The Government in the domestic economy collects revenue taxes from firms. These taxes are then redistributed to households in the form of lump-sum transfers TR (the government subsidy is used to eliminate the steady-state mark-up distortions). This is done in a way that in each period there is a balanced budget.

$$\int_0^n (\tau P_{H,t}(f) Y_t(f)) df = \int_0^n TR_t(f) df \tag{2.38}$$

2.3.5 Stochastic Environment and Equilibrium

The equilibrium of the small open economy consists of:

1) allocations and wages for home consumers:
   C_t, I_t, B_t, W_t
2) allocations and prices for home firms:
   $K_{t-1}, N_t, P_{H,t}$
3) allocations and prices for foreign firms:
   $K_{t-1}^*, N_t^*, P_{H,t}^*$
4) rental rate for capital: R_t^K
5) fiscal policies,

such that households and firms' allocations solve the households' and firms' problems (i.e., the first order conditions), and that the following market clearing conditions are satisfied:

(2.39) $$B_t = 0$$

(2.40) $$N_t^d = N_t^s$$

Market clearing for domestic variety *f* must satisfy[77]:

(2.41) $$Y_{H,t}^d(f) = n\left(C_{H,t}(f) + I_{H,t}(f)\right) + (1-n)\left(C^*{}_{H,t}(f^*) + I^*{}_{H,t}(f^*)\right)$$

which using individual demand equations for domestically consumed and exported home goods (i.e., eq (2.11)-(2.12) and their counterparts for the Home export), and remembering that LOOP holds in the model, and that $1\text{-}\lambda = (1\text{-}n)\omega,\ \lambda = 1\text{-}(1\text{-}n)\omega$, $\lambda^* = n\omega^*$, $1\text{-}\lambda^* = 1\text{-}n\omega^*$ (and that n→0), can be re-written as:

(2.42)
$$\begin{aligned}
Y_{H,t}^d(f) &= \frac{n\lambda}{n}\left(\frac{P_{H,t}(f)}{P_{\mathrm{H},t}}\right)^{-\sigma_H}\left(\frac{P_{H,t}}{P_t}\right)^{-\phi}\left(C_t + I_t\right) + \\
&+ \frac{(1-n)(\lambda^*)}{n}\left(\frac{P_{H,t}^*(f^*)}{P_{H,t}^*}\right)^{-\sigma_H}\left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\phi}\left(C_t^* + I_t^*\right) = \\
&\overset{n\to 0}{=} (1-\omega)\left(\frac{P_{H,t}(f)}{P_{H,t}}\right)^{-\sigma_H}\left(\frac{P_{H,t}}{P_t}\right)^{-\phi}\left(C_t + I_t\right) + \left(\omega^*\right)\left(\frac{P_{H,t}^*(f^*)}{P_{H,t}^*}\right)^{-\sigma_H}\left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\phi}\left(C_t^* + I_t^*\right) = \\
&= \left(\frac{P_{H,t}(f)}{P_{H,t}}\right)^{-\sigma_H}\left(\frac{P_{H,t}}{P_t}\right)^{-\phi}\left[(1-\omega)\left(C_t + I_t\right) + \left(\omega^*\right)\left(\frac{1}{Q_t}\right)^{-\phi}\left(C_t^* + I_t^*\right)\right]
\end{aligned}$$

Since in a symmetric equilibrium, each domestic producer charges the same price and produces the same level of output, so that $Y_{H,t}^d(f) = Y_{H,t}^d$ and $P_{H,t}(f) = P_{H,t}$, (2.42) can be further simplified:

(2.43) $$Y_{H,t}^d = \left(\frac{P_{H,t}}{P_t}\right)^{-\phi}\left[(1-\omega)\left(C_t + I_t\right) + \omega^*\left(\frac{1}{Q_t}\right)^{-\phi}\left(C_t^* + I_t^*\right)\right]$$

[77] The aggregate consistency condition requires that individual and per capita variables coincide for all t. Also, notice that given the relationship (2.4) and (2.9) and their counterparts for Home export, (2.41) can be expressed as $Y_{H,t}^d = C_{H,t} + I_{H,t} + C_{H,t}^* + I_{H,t}^*$.

Market clearing conditions are as follows. Condition (2.39) requires that since only domestic consumers have access to domestic bonds, the net supply of these bonds must be zero in equilibrium. Condition (2.40) states that, in equilibrium, labour market requires equalization of total labour demand and supply. Goods' market equilibrium condition (2.41) states that total demand in the H sector comprises of demand for goods demanded by domestic and foreign consumers $\left(C_{H,t}, C^{*}_{H,t}\right)$ as well as domestic and exported investment goods $\left(I_{H,t}, I^{*}_{H,t}\right)$.

The exogenous driving forces in the economy include technology, quality and preference shocks (consumption and labour supply), which follow stochastic processes:

(2.44) $$\log A_{t+1} = \rho_A \log A_t + \varepsilon_{A,t+1}$$

(2.45) $$(\iota - 1)\log \chi_{t+1} = \rho_{\chi_H} (\iota - 1)\log \chi_t + \varepsilon_{\chi,t+1}$$

(2.46) $$\log \Upsilon_{C,t+1} = \rho_{\Upsilon_C} \log \Upsilon_{C,t} + \varepsilon^{\Upsilon_C}_{t+1}$$

(2.47) $$\log \Upsilon_{N,t+1} = \rho_{\Upsilon_N} \log \Upsilon_{N,t} + \varepsilon^{\Upsilon_N}_{t+1}$$

(2.48) $$\log A^{*}_{F,t+1} = \rho_{A^{*}_F} \log A^{*}_{F,t} + \varepsilon^{A^{*}_F}_{t+1}$$

Preference shocks are introduced to allow investigation of the effects of changes on the demand side of the economy in a non-monetary framework.

The steady-state is solved analytically 'by hand'. Then, the standard log-linearization techniques are used in order to analyze the dynamics of the model. The software package Dynare (see Collard and Juillard (2003) for details) is used to take a first order Taylor approximation of the model's structural equilibrium equations around this deterministic steady state. Subsequently, Dynare assesses whether the Blanchard-Kahn conditions are met (i.e., the necessary condition for the uniqueness of a stable equilibrium in the neighbourhood of the steady state is that there are as many eigenvalues larger than one in modulus as there are forward looking variables). Then the program calculates the solution to the linearized system of equations. The model is calibrated to match Polish variables such as output, consumption, investment, employment as well as several key international variables.

2.3.6 Some definitions and identities

Since the small open economy model is analysed in real terms, all domestic prices are normalized on P_t, the home CPI index.

Given that in the model the law of one price holds, but PPP is violated due to the presence of home bias, it is true that[78]:

(2.49) $$p_{H,t} = P_{H,t} / P_t = (P_t^* / P_t)(P_{H,t} / P_t^*) = Q_t p_{H,t}^*$$

and

(2.50) $$p_{F,t} = Q_t p_{F,t}^*$$

However, since the model considers the small open economy case, $p_{F,t}^* = 1$ (i.e. given that the relative size of Home is negligible relative to the rest of the world, and the fact that LOOP holds, $P_{F,t} = P_{F,t}^* = P_t^*$), and thus $p_{F,t} = Q_t$.

Terms-of-trade in the model is defined as a price of foreign tradable good in terms of home tradable good:

(2.51) $$\mathrm{T_t} \equiv P_{F,t} / P_{H,t}$$

and in the foreign country:

(2.52) $$\mathrm{T}_t^* = P_{H,t}^* / P_{F,t}^*$$

Again, because LOOP holds in the model, $\mathrm{T}_t^* = P_{H,t} / P_{F,t}$, this implies that:

---

[78] Country consumer price index (2.3) can be re-written as follows: $\frac{P_{H,t}}{P_t} = \left((\lambda + (1-\lambda) \left(\frac{P_{F,t}}{P_{H,t}} \right)^{1-\phi} \right)^{\frac{1}{\phi-1}} = \left((\lambda + (1-\lambda) \left(T_t \right)^{1-\phi} \right)^{\frac{1}{\phi-1}}$. Analogous equation can be derived for the foreign country.

(2.53) $$\mathrm{T_t} = 1/\mathrm{T}_t^*$$

which is the same as to say that foreign terms-of-trade are reciprocal to domestic terms-of-trade.

Now, assuming that home and foreign consumers prefer to consume locally produced goods to the same degree (i.e. symmetric home bias is observed, $\lambda = 1 - \lambda^*$), and remembering that $P_{F,t}^* = P_t^*$ because of the SOE assumption, and the fact that LOOP holds in the model (i.e., $P_{F,t} = P_{F,t}^*$ and $P_{H,t} = P_{H,t}^*$), one can link the terms of trade and the real exchange rate in the following way:

(2.54) $$Q_t = \frac{P_t^*}{P_{F,t}^*}\left(\frac{P_t}{P_{H,t}}\right)^{-1} T_t = \left(\frac{P_{H,t}}{P_t}\right) T_t = p_{H,t} T_t$$

Given that $p_{H,t} = \left((\lambda + (1-\lambda)T_t^{1-\phi}\right)^{\frac{1}{\phi-1}} \equiv f(T_t)$ (see footnote 78), the real exchange rate is a function of terms-of-trade:

(2.55) $$Q_t = f(T_t)T_t = \left((\lambda + (1-\lambda)T_t^{1-\phi}\right)^{\frac{1}{\phi-1}} T_t = \left(((1-\lambda) + \lambda T_t^{\phi-1}\right)^{\frac{1}{\phi-1}}$$

which in a loglinear form reads as:

(2.56) $$\widehat{Q}_t = \lambda\left(\widehat{P}_{F,t} - \widehat{P}_{H,t}\right) = (1-\omega)\left(\widehat{P}_{F,t} - \widehat{P}_{H,t}\right)$$

where the variables with the hat represent the log deviations from the steady state.

Notice that in the absence of home bias (i.e. when $\lambda \to 0$), the volatility of the real exchange rate is constant. This is because, in this case, even if the small open economy is fully open, its consumption basket collapses to the one of the rest of the world (i.e. $C_t = C_{F,t}$), which, in turn, converges to a closed economy.

2.4 UTILITY FUNCTION, PARAMETRISATION AND SIMULATION

2.4.1 Baseline calibration

As in 2.3.2, it is assumed that household preferences are additively separable and that the utility function is of the form described by (2.29). Structural parameters, where possible, are calibrated in a way that resembles the structure of the Polish economy. The chosen values were then cross-checked with values selected in previous work done on NMSs of the EU (i.e., Laxton and Pesenti (2003), Ravenna and Natalucci (2003, 2007), Lipińska (2008, 2008a), and Kolasa (2009)). For these parameters where no reliable values could be obtained for Poland or any other NMS, the values accepted in the business cycle literature (in particular for small open economies) are used. All the selected parameters are presented in Annex B.4, Table B.4. 1.

Table 2.4.1 below presents the decomposition of Polish GDP together with the steady-state results obtained from the baseline calibration (i.e. the calibration in which parameters gathered in Annex B.4, Table B.4. 1 were applied):

Table 2.4.1 Structure of the Polish and Model Economies

Structure	Polish economy	Steady-state
I/GDP	21	19
C/GDP	82	81
M/GDP	33	30

Note: I – real investment, C – real consumption, M – import, GDP – Gross Domestic Product. Columns, 'Polish economy' and 'Steady-state', are expressed in percent of GDP. The values were calculated over the period 1995-2008.

Source: Author's calculation based on the OECD data and the steady-state solution of the model.

The intertemporal discount factor equals 0.99, which implies a steady-state annual real interest rate of 4 per cent, the standard value in the literature (the steady-state inflation rate is assumed to be 0). The coefficient of relative risk aversion ρ corresponds to that in Chari et al. (2002) and is set to 5. Even if this is a rather high value, it is justified on the basis that countries with relatively little wealth and high unemployment rates (like Poland) are more risk averse. In such countries, households' preferences for consumption smoothing are higher, which means that they are less willing to reduce labour supply when wages fall.

For the baseline model calibration, Frisch elasticity of labour supply is chosen to be 0.3. There seem to be relatively little consensus as to the value of this elasticity in the literature (as pointed out by Canzoneri et al. (2008) it ranges from 0.05 to 0.35). In general, it seems reasonable to assume higher values of Frisch elasticity as in a country with borrowing constraints (like Poland), lower values would mean that households would have to reduce their consumption drastically if they did not increase labour supply in response to falling wages. Parameter η_0 is chosen so that, in the steady state, households allocate 1/3 of their time to work. The elasticity of substitution between home and foreign tradable goods ϕ, equals 2. This value is conventional for IRBC models and suggests that home and foreign tradable goods are close substitutes[79]. Price elasticity of demand faced by each producer σ equals 6. This, together with the revenue taxes of 0.1[80], ensures that the steady-state markup comes to 1.33, a plausible value in the literature (Morrison (1994) and Domowitz et al. (1988), in Laxton and Pesenti (2003), estimate the possible markup values between 1.2 and 1.7). The home bias parameter λ is set to be 0.7 (and lies between the 0.8 value put by Ravenna and Natalucci (2007) for the Czech economy, and 0.6

[79] There is mixed evidence on the true value of this elasticity. Some studies employing Bayesian estimation of fully structural DSGE open macro models seem to support a range between 1.5 and 2 (see, for example, Adolfson et al. (2005)). Also, Faruqee et al. (2005) assume a value of 2.5 (this number is also used in the IMF's Global Economic Model). Obstfeld and Rogoff (2000) based on micro empirical-trade literature suggest even higher values for this elasticity, claiming that a high elasticity of substitution can explain the observed large home bias in trade. Nonetheless, a lot of current DSGE literature (among others Corsetti et al. (2008), Theonissen (2006)) relies on the values below 2. There also exists Bayesian studies (e.g., Rabanal and Tuesta (2005) or de Walque, Smets and Wouters (2005)), which support the values below 1.

[80] Calculated as GDP at 1995 constant prices less GVA at 1995 constant prices for Poland and averaged over 1995 Q1-2008 Q1 (source: author's calculation based on the OECD data).

chosen by Kolasa (2009) for Poland), which implies a degree of openness, ω, of 0.3. This matches the 0.3 share of imports in Polish GDP[81].

The capital share for the intermediate goods producers are set to be 0.35 (which is similar to the value of 0.42 chosen by Ravenna and Natalucci (2007)). The steady-state rate of capital depreciation rate δ is set to 10 per cent annually (see, for example, Allard et al. (2008)). The adjustment cost in changing the capital stock employed by each intermediate good producer, ν, is chosen to match the volatility of investment in the Polish economy (i.e. in the baseline calibration it is equal to 15).

Given that there are no available estimates of the parameter ι governing the impact of quality changes on the marginal cost of firms, this value is set below 1 (or more precisely to 0.1)[82]. This is because, if $\iota > 1$, then the unit cost of production is a decreasing function of quality (i.e., quality improvements in the home sector lower the marginal cost); if $\iota < 1$, marginal cost of the firm increases together with quality improvements (i.e., more labour / capital input is required to produce better quality products); and finally if $\iota = 1$, then quality improvements have no impact on the production process. The most realistic scenario faced by Polish producers is the case when $\iota < 1$.

Calibration of shocks

The lack of a long data span as well as the lack of reliable data on capital and employment[83] make it difficult to estimate reliable productivity processes for Poland, and thus the variances (and covariances between Poland and the eurozone) of productivity innovations. The empirical studies on the issue are scarce[84].

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[81] Different measure of openness were also looked at, i.e. the share of export and import in Polish GDP. As this would imply a lack of consumption home bias, the import-to-GDP ratio was relied on.
[82] Different values below one were also tried. Since they did not impact the results significantly (neither in terms of the direction of the real exchange rate movements nor in terms of model moments), only the results for the baseline magnitude are presented in Table 2.4.3, Section 2.4.3.
[83] The data on capital for Poland is virtually non-existent. Due to methodological changes, the Eurostat data on Polish employment begins only from 2000Q1 (data available before that was gathered only in four months of the year and was not recalculated to the quarterly basis).
[84] The notable exception is Zienkowski (2000) who estimates productivity of labour and total factor productivity in Poland by sections of NACE. He reports that the average growth rate of labour

To the author's best knowledge, the study by Kolasa (2009) is the only study to investigate the differences in parameters describing agents' decision-making in Poland and in the euro area, as well as volatility and synchronization of shocks impacting both economies (his model is a multi-sector model comprising tradable and nontradable good). In his Bayesian estimation of the DSGE model for Poland, he chooses the priors for standard deviations of the stochastic disturbances that are three times larger than in the euro area. His choice is supported by the cross-country differences in volatility of the observable variables used in the estimation. The results (posterior estimates of shock volatilities) confirm that the magnitude of shocks impacting Poland is substantially larger than the size of shocks identified for the euro area (on average, the shocks are more than three and a half times larger than those hitting the euro area. The smallest discrepancy was estimated for the productivity shocks in the nontradable sector, but still its standard deviation in Poland turns out to be more than two and a half times larger than in the euro area). In terms of persistence of the productivity improvements, Kolasa's (2009) finds that the AR(1) coefficients for Poland are rather homogenous when compared with the euro area.

Despite difficulties described above, an attempt was made to estimate the persistence of the productivity process and the variance of its innovation. First, in the absence of available data for capital, the productivity process was approximated as a quasi-Solow residual, holding capital stock constant. In particular, the productivity series was constructed in the following way (see, for example, Heathcote and Perri (2002)):

$$\ln(A_{H,t}) = \ln(Y_{H,t}) - (1-\alpha)\ln(N_{H,t})$$

where α is the share of capital and it is assumed to be 0.35.

---

productivity in manufacturing in Poland between 1992 and 1998 was equal to around 10.7 percent, ranging from 37 percent to 4.4 percent depending on the branch, while total factor productivity was increasing at the rate of 8.6 percent. He also points out that the period 1992-1998 can be divided into two subperiods: 1992-1994 and 1995-1998. The growth rates of productivity were distinctly higher in the first subperiod than in the second one (13.2 percent versus 8.9 percent). Unfortunately, he does not provide the numbers for variances or persistence associated with the stochastic productivity series.

To calculate the above series, the data on employment and gross value added for the years 2000Q1-2008Q4 was sourced from Eurostat[85]. Next, A_H series were detrended using a Hodrick-Prescott (HP) filter. Having constructed productivity series, the exogenous process for productivity was specified as a lognormal AR(1) process. Although the more standard way of specifying the exogenous processes for productivity between the two economic zones is of the form of a bivariate VAR(1) model, this strategy was not executed here. This is because of the relatively weak correlation between structural shocks within the euro area, the evidence provided by Jondeau and Sahuc (2006) (in Kolasa (2008, 2009)). Specifying exogenous process for productivity as a lognormal AR(1) process implies zero correlation between the shocks and no spillover effects.

Given that the estimated AR(1) coefficient for the lognormal productivity process turned out to be very low (0.45), that such a low value resulted in a volatility of output which is not observed in the Polish data, and that low persistence of the productivity process is inconsistent with Kolasa's (2008, 2009) findings (he finds that the AR(1) coefficients for Poland are rather homogenous when compared with the euro area), an AR(1) coefficient for the productivity process for Poland was scaled up to match the volatility of its output in years 1995Q1-2008Q1[86].

The quality shock was estimated in the same manner. In the absence of available priors for quality adjustments, available data on export unit values is used. There are few papers which take into account quality changes within the dynamic stochastic general equilibrium framework. The exceptions (Roeger et al. (2008), Corsetti et al. (2008)) either explicitly introduce R&D sector into the model or allow the possibility of trade in new varieties (with an entry cost)[87]. However, this approach is not appropriate for the NMSs, where R&D expenditures are not significant and are mostly borne by multinational firms in their country of origin (see

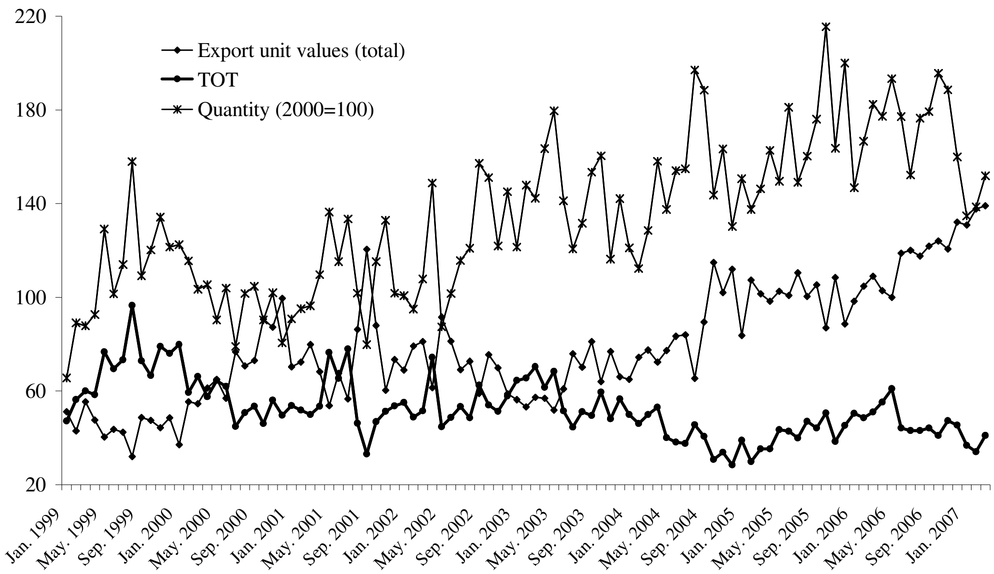
[85] Due to methodological changes, the reliable Eurostat data begins only from 2000Q1 (data available before that was gathered only in four months of the year and was not recalculated to the quarterly basis).

[86] One should also keep in mind the low quality of the Polish data on employment and the fact that high persistence of productivity shocks is generally assumed in the RBC literature.

[87] Aiginger (2000) lists the following inputs to quality upgrading: R&D expenditures, skilled labour, sophisticated capital, information and communication technology, extra stage of processing as well as knowledge service input.

van de Klundert and Smulders (1998)). Therefore, a better way to approximate quality changes in the NMSs is to use export unit values (gross value of exports divided by quantity) as an indicator of quality. Aiginger (1997) suggests that for many industries, unit values are a good indicator of quality. At the same time, he does point out that higher unit values could simply reflect high costs of exports. However, even if unit values only reflected high costs, quantity exported would have to be low for a high cost country. Since in the NMSs terms-of-trade (defined as a relative price of foreign and domestic tradable good) improvements are combined with good export performance, increasing unit values of export should reflect quality improvements in those countries and not increasing costs. Figure 2.1 illustrates the trends in export unit values, quantity exported as well as terms-of-trade between Poland and the group of 25 EU countries between January 1999 and March 2007. It is clear that increases in export unit values are accompanied by increases in quantities exported. This suggests that export unit values can be used as a proxy for quality changes in a country like Poland.

Figure 2.1. Trade Indicators, Poland



Source: Author's calculation based on OECD data.

The euro area economy-wide productivity shock was taken from Mykhaylova (2009). Finally, the starting point of reference for the assumptions on consumption and labour preference shocks (and their persistence) comes from Laxton and Pesenti (2003)[88].

The calibrated magnitudes of shocks and their persistence are presented in Table 2.4.2 below:

Table 2.4.2 Volatilities of shocks

Shocks to:	Productivity	Quality	Cons. Prefer.	Labour Prefer.	Foreign Prod.
E(ε2)	1.08E-04	1.69E-04	1.60E-05	1.60E-03	1.60E-05
AR	0.95	0.95	0.70	0.95	0.95

Source: Author's calibration based on own estimates as well as values proposed by Laxton and Pesenti (2003) and Mykhaylova (2009). For details, see the discussion in the main text.

[88] Given that the magnitude of labor preference shock proposed by Laxton and Pesenti (2003) resulted in the too high volatility of hours worked as well as its too high correlation with output when compared with the data, they were scaled down accordingly.

Admittedly, these are only rough guesses, but they do provide some indication of shock processes in the Polish economy. Also, given the uncertainty assigned to the proposed values of shocks and their persistence, a sensitivity analysis is performed with respect to some of them.

2.4.2 Simulation Results

In what follows, before matching the moments of the variables calculated for the Polish economy, the effects of individual 1 percent positive shocks are graphed as impulse response functions (with all the AR(1) coefficients equal to 0.95). The purpose of this exercise is to find out in which direction the shocks affecting the economy pull the real exchange rate. Five types of stationary shocks are considered: productivity (home and foreign), quality, consumption preference, and labour disutility. The shocks are assumed to be non-correlated and to follow a first order autoregressive process:

$$A_{t+1} = \Omega A_t + \varepsilon_t$$

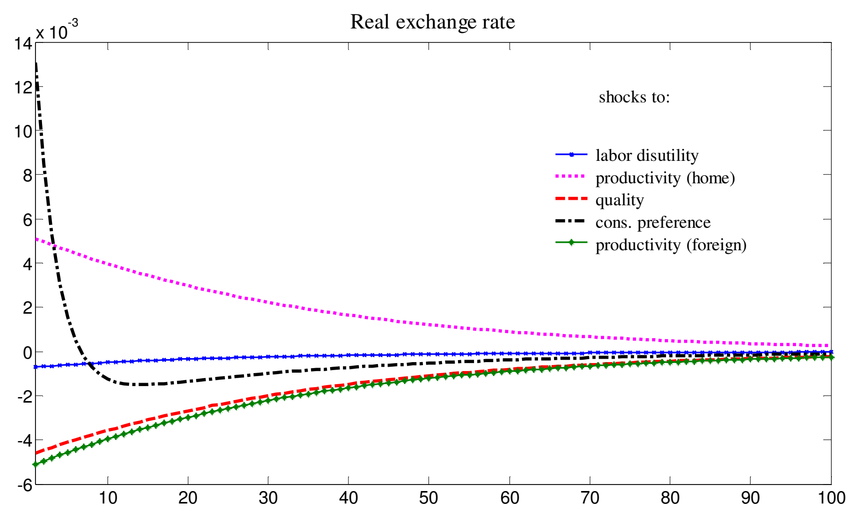
where A_t is a vector of shocks $\left[A_{H,t}, A_{\chi,t}, A_{\Upsilon_{C,t}}, A_{\Upsilon_{L,t}}, A_{F^*,t}\right]$, and Ω is a 5x5 matrix of AR(1) coefficients. The disturbances to A_t are $\left[\varepsilon_{A,t}, \varepsilon_{\chi,t}, \varepsilon_{\Upsilon_C,t}, \varepsilon_{\Upsilon_L,t}, \varepsilon_{F^*,t}\right]$ and the variance-covariance matrix is $V\left[\varepsilon_t\right]$.

In particular:

$$\Omega = \begin{pmatrix} 0.95 & & 0 \\ & \ddots & \\ 0 & & 0.95 \end{pmatrix} \qquad V\left[\varepsilon_t\right] = \begin{pmatrix} 0.01 & & 0 \\ & \ddots & \\ 0 & & 0.01 \end{pmatrix} \tag{2.57}$$

As Figure 2.2 demonstrates, within the model, productivity improvements lead to real exchange rate depreciation. This is because this type of shock causes decreases in the price of traded Home goods, leading – through home bias - to terms-of-trade and real exchange rate deterioration (as equation (2.56) indicates, the real exchange rate is a positive function of terms-of-trade). On a contrary, a positive quality shock does lead to the appreciation of the real exchange rate. This is consistent with the empirical findings of Egert and Lommatzsch (2004). Initially the consumption preference shock pulls the real exchange rate towards depreciation, after which the real exchange rate appreciates. This is because even though the expansion of output is observed (driven by higher consumption and increased labour input) real wages go down (due to price increases). The labour disutility shock causes unambiguous appreciation of the real exchange rate. This is because an increase in the weight of leisure in consumers' utility causes labour input to decline. This translates into lower consumption, investment and output. Real wages, and thus prices increase. The real exchange rate also appreciates unambiguously when improvements in foreign productivity are observed.

Figure 2.2. Orthogonalized Responses to Stationary Disturbances



Source: Author's calculations

Matching the moments

This section addresses the performance of the model in respect of matching the moments observed in for the Polish economy data. Table 2.4.3 and Table 2.4.4 present the business-cycle properties of the Polish data together with the results obtained from model simulations. The theoretical and empirical business-cycle statistics were obtained using the Hodrick-Prescott (HP) filter applied to quarterly time-series (with the smoothing parameter λ=1600). The data for Poland was sourced either form Eurostat or OECD. Given that the role of the elasticity of substitution between H and F tradable goods ϕ in determining the behaviour of the real exchange rate is well documented in the literature (e.g. Corsetti et al. (2008), Theonissen (2006)), and the fact that there is no consensus on the value of this parameter (neither there exists estimates of this elasticity for the NMSs of the EU), three different values were tried and discussed below. Sensitivity analysis was also performed with respect to the magnitude of the preference shock as well as the persistence of the productivity shock. Also, to see the impact of an individual shock on the model performance, Table 2.4.3 reports the results when the shocks are added one-by-one, starting from the productivity shock only. The results are presented below.

As in the case of the business-cycle data for developed countries, in Poland consumption is less volatile than output. Investment is almost 5 times as volatile as output. Employment is slightly more volatile than output. These volatilities are comparable (although on the higher end) with the results usually reported for the EMU countries. Still, the volatilities of international variables (terms-of-trade, trade balance and RER) are higher.

Table 2.4.3: Model and Data Volatility

	Standard Deviation										
		model									
	data	all shocks			high pref.	p	p+q	p+q+f	p+q+f+l	low qual.	all shocks
		ϕ=2	ϕ=0.6	ϕ=0.1	ϕ=2	ϕ=0.1	ϕ=0.1	ϕ=0.1	ϕ=0.1	ϕ=0.1	ϕ=2
Variable		$A_H(1)$=0.95									$A_H(1)$=0.7
GDP	1.34	2.35	2.00	1.54	2.41	1.08	1.49	1.49	1.57	1.39	2.23
Consumption	1.06	0.30	0.53	0.85	0.37	0.40	0.68	0.68	0.77	0.73	0.29
Investment	6.52	6.55	6.57	6.49	6.54	5.41	6.50	6.50	6.51	6.55	6.48
Employment	1.48	1.46	1.23	1.32	1.77	0.45	0.85	0.86	1.31	1.21	1.33
Terms-of-Trade	4.47	1.87	3.80	6.24	2.31	2.84	4.89	5.04	5.65	5.39	1.80
Trade balance[a]	1.46	1.25	0.44	2.06	1.71	1.10	1.75	1.80	1.97	1.79	1.23
Real exchange rate[b]	5.30	1.31	2.66	4.37	1.61	1.99	3.42	3.53	3.95	3.77	1.26

Note: The column titled ‘all shocks’ presents the model simulations with all the shocks being switched on for different values of trade elasticity. The column titled ‘high pref.’ corresponds to simulations when higher magnitudes of a consumption preference shock are tried. Columns ‘p’, ‘p+q’, ‘p+q+f’, and ‘p+q+f+l’ report results of simulations when productivity, quality, foreign productivity, and labour preference shocks are added one-by-one. ‘low qual.’ column reports results of simulations with lower magnitudes of a quality shock. Finally, the last column looks at the model results when the memory of the productivity shock is lowered; a. Statistics for net exports are based on the HP-filtered ratio of real net exports to the real GDP; b. Statistics for the empirical RER are based on the HP-filtered real effective exchange rate.

Source: Author’s calculation based on the Eurostat and OECD data and the model simulations;

Comparing actual volatilities with those predicted by the model when the elasticity of substitution between H and F tradable goods ϕ is set to 2, it is obvious that except for the number for employment, investment and to a large degree trade balance, modelled volatilities do not match the data. Output is too volatile, and consumption and international variables are significantly less volatile. Moreover, terms-of-trade are more volatile than in the RER (this is not surprising given that real exchange rate is only a fraction of terms-of-trade, see eq (2.56)). When the elasticity of substitution between H and F tradable goods is lowered to 0.6, the business-cycle statistics - except for employment – are slightly more comparable with the data. However, the performance of international variables – except for the trade balance – improves considerably. Therefore, given that lowering ϕ improves the fit of the model, in the next step, its value was lowered to 0.1. This time all the variables but the terms-of-trade (which became too volatile) came relatively close to what is observed in the data. Increasing the magnitude of the preference shock (to 0.009; see column ‘high pref.’ in Table 2.4.3) for the value of ϕ equal to 2 makes all the variables more volatile. Nonetheless, the gain in terms of the fit of the consumption is minimal.

Simulation of the model with subsequent shocks switched off, shows that output is mainly moved by productivity and quality shocks. In addition to these three supply side shocks (domestic and foreign productivity as well as domestic quality), consumption and employment are governed by preference and labour disutility shocks, respectively. Surprisingly, the impact of the consumption preference shock on consumption volatility is not as big as it could be expected, and is almost equivalent to the impact of the labour preference shock on the volatility of this variable. International variables become more volatile each time a new shock is added. However, they are mainly moved by domestic productivity and quality preference shocks. Finally, given the lack of reliable estimates for the magnitude of the quality shock, its size was lowered to 0.007. This improved the fit of the model output, terms of trade and trade balance, at the expense of the fit of the rest of variables.

Table 2.4.4: Model and Data Autocorrelations and Correlations

	Autocorrelation			Corr with GDP				
	data	model, ϕ=2,		data	model			
Variable		AH(1)=0.95	AH(1)=0.75		ϕ=2	ϕ=0.6	ϕ=0.1	low qual.
GDP	0.68	0.71	0.66	1.00	1.00	1.00	1.00	1.00
Consumption	0.41	0.69	0.66	0.61	0.77	0.91	0.93	0.87
Investment	0.77	0.62	0.59	0.78	0.54	0.78	0.94	0.92
Employment	0.94	0.70	0.59	0.83	0.50	0.14	-0.39	-0.19
Terms-of-Trade	0.05	0.68	0.64	0.29	0.92	0.91	0.90	0.84
Trade balance[a]	0.55	0.64	0.60	-0.24	0.78	-0.88	-0.93	-0.90
Real exchanage rate[b]	0.80	0.68	0.64	-0.02	0.92	0.91	0.90	0.84

Note: 'low qual.' column reports results of simulations with lower magnitudes of a quality shock. 'AH(1)=0.95' and 'AH(1)=0.75' columns report the model results when the memory of the productivity shock is 0.95 and 0.75, respectively. a. Statistics for net exports are based on the HP-filtered ratio of real net exports to the real GDP; b. Statistics for the empirical RER are based on the HP-filtered real effective exchange rate.

Source: Author's calculation based on the Eurostat and OECD data and the model simulations;

In terms of the first-order autocorrelation coefficients (AR(1)) of the chosen variables of the Polish data (see Table 2.4.4), they range from 0.05 to 0.94, with the highest persistence recorded for employment and real exchange rate. Comparing these coefficients with those obtained from the model (as they are almost identical for different values of elasticity of substitution as well as other sensitivity checks, only the statistics for $\phi = 2$ are presented), the most significant discrepancy is recorded for the terms-of-trade variable – the data exhibits no memory and the model predicts it to be quite high and equal to 0.71. Lowering the elasticity of substitution between home and foreign tradable goods did not change the persistence of the model variables. Lowering the persistence of the home productivity shock to 0.75 did diminish the memory of the model, but not significantly (with the larger impacts on employment and investment).

The model correlation of the investigated business cycle variables with the output, for the $\phi = 2$, is of the correct sign. In terms of international variables, the correlation of output with terms-of-trade seems to be too strong. The largest discrepancy is however observed between the co-movements of trade balance and the output and the RER and output; it is very high in the model and either negative or nonexistent in the data. When ϕ is set to 0.6, the sign of correlation between trade balance and the output becomes correct, but the relationship between the RER and output is still of the wrong sign. Lowering ϕ even further to 0.1 does not alter model correlations much. However, it does produce a negative correlation between output and employment – something not observed in the data.

In respect of the contribution of particular shocks to the variance of the Polish real exchange rate (see Table 2.4.5 below), the model predicts that the quality shock is the main factor responsible for RER movements for the baseline model as well as for the models when the elasticity of substitution between home and foreign tradable goods is lowered. Nonetheless, the productivity and preference shocks are also fairly important (although the productivity shock seems to be somewhat more important in all cases, except for when the preference shock is increased). The labour preference shock moves the RER in a little more than 10 percent. Its importance diminishes when the size of the quality shock is increased. The foreign productivity shock does not add much to the RER volatility. These results confirm that quality changes may be responsible for the real exchange rate appreciation in the NMSs[89]. However, it is also clear that the consumption demand shock cannot be ignored.

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[89] Variance decomposition for the RER was almost the same for the lower value of the elasticity of substitution between H and F goods and thus is not presented.

Table 2.4.5: Variance decomposition

RER	ε_A	ε_χ	ε_{Υ_C}	ε_{Υ_L}	ε_{F^*}
baseline	27.96	35.39	21.60	10.92	4.14
ϕ=0.6	28.97	36.67	18.76	11.32	4.29
ϕ=0.1	30.87	39.08	13.42	12.06	4.57
lower quality shock	36.92	22.40	20.80	14.42	5.46
higher preference shock	22.45	28.42	37.04	8.77	3.32

Note: Author's calculation. ε_A (ε_{F^*}) and ε_χ represent domestic (foreign) productivity and quality shocks, respectively. ε_{Υ_C} and ε_{Υ_L} stand for consumption and labour preference shocks.

2.5 CONCLUSIONS

In this chapter a basic one-sector small open economy model of the real exchange rate determinants for the NMSs of the EU was proposed. Two questions were asked. First, it was asked to what extent quality changes can be attributed to the observed persistent appreciation of real exchange rates in the NMSs in general, and in Poland in particular. Second, it was asked whether a basic version of the SOE-DSGE IRBC model with only tradable goods can generate the highly volatile and persistent real exchange rates observed in the NMSs.

The results broadly show that a basic model featuring only tradable goods, and in which real exchange rate fluctuations are exclusively caused by the presence of home bias in consumption, performs poorly in terms of matching the moments of the Polish data for the conventional levels of the elasticity of substitution between home and foreign tradable goods. In particular, it was shown that, within the model, real shocks are not able to explain the recorded variability of the Polish terms-of-trade and real exchange rate unless very low levels of this elasticity are assumed. However, for such levels of elasticity, terms-of-trade becomes too volatile and the model produces negative correlation with employment. Nevertheless, the model performs quite well in terms of mimicking RER persistence. It also highlights that quality changes could be consistent with appreciating real exchange rate in the NMSs.

ANNEX B.1. PRICE INDEX AND DEMAND FUNCTIONS

Households need to decide how to allocate consumption home and foreign goods. The CES price aggregator P_t (equation (2.3) in the main text) can be derived from the following household minimum expenditure problem:

$$\min_{C_t} P_t C_t$$

(B1) $$\text{s.t. } C_t = \left[(\lambda)^{\frac{1}{\phi}} C_{H,t}^{\frac{\phi-1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}} C_{F,t}^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}$$

(B2) $$L = P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + \mu_t \left[C_t - \left[(\lambda)^{\frac{1}{\phi}} C_{H,t}^{\frac{\phi-1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}} C_{Ft}^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} \right]$$

Note: Solving for the Lagrangian multiplier μ_t is equivalent to solving for the home goods price index P_t since μ_t is a proxy for the amount required to purchase one extra unit of consumption basket C_t (i.e., $\mu_t = P_t$).

First order conditions are:

(B3) $$\frac{\partial L}{\partial C_{\mathrm{F,t}}} : \ \mathrm{P_{F,t}} - \mu_t (1-\lambda) C_t^{\frac{1}{1-\phi}} \left(\mathrm{C_{F,t}}\right)^{\frac{-1}{\phi}}$$

(B4) $$\frac{\partial L}{\partial C_{H,t}} : \ P_{H,t} - \mu_t \lambda C_t^{\frac{1}{1-\phi}} \left(C_{H,t}\right)^{\frac{-1}{\phi}}$$

(B5) $$\frac{\partial L}{\partial \mu_t} : \ \left[(\lambda)^{\frac{1}{\phi}} C_{H,t}^{\frac{\phi-1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}} C_{Ft}^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} = C_t$$

(B3), (B4), (B5) can be re-written as:

(B3a) $$C_{F,t} = (1-\lambda)\left(P_{F,t}\right)^{-\phi}\mu_t^{\phi}C_t$$

(B4a) $$C_{H,t} = \lambda\left(P_{H,t}\right)^{-\varepsilon}\mu_t^{\phi}C_t$$

(B5a) $$\left[(\lambda)^{\frac{1}{\phi}}C_{H,t}^{\frac{\phi-1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}}C_{Ft}^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}} = C_t = 1$$

where (B3a) and (B4a) are final demand functions for home and foreign tradable consumption goods.

Now, substituting (B3a) and (B4a) into (B5a), it is possible to solve for μ_t and thus P_t (which is the equation (2.3) in the main text).

Individual Demand Functions

Individual demand functions for the representative consumer *s* are obtained from the optimal allocation of expenditure across H, and F goods.

(B6)
$$\min_{C_{H,t}} \int_0^n P_{H,t}(f)C_{H,t}(f)df$$
$$s.t.\ C_{H,t} \equiv \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma_H}} \int_0^n C_{H,t}(f)^{\frac{\sigma_H-1}{\sigma_H}} df\right]^{\frac{\sigma_H}{\sigma_H-1}}$$

(B7) $$L = \int_0^n P_{H,t}(f)C_{H,t}(f)df + \mu_{H,t}\left[C_{H,t} - \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma_H}} \int_0^n C_{H,t}(f)^{\frac{\sigma_H-1}{\sigma_H}} df\right]^{\frac{\sigma_H}{\sigma_H-1}}\right]$$

First order conditions are:

(B8) $$\frac{\partial L}{\partial C_{H,t}(f)}:\ \mathrm{C}_{H,t}(f) = \frac{1}{n}\mu_{H,t}^{\sigma_H}C_{H,t}\left(P_{H,t}(f)\right)^{-\sigma_H}$$

(B9) $$\frac{\partial L}{\partial \mu_{H,t}}: \qquad C_{H,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma_H}} \int_0^n C_{H,t}(f)^{\frac{\sigma_H - 1}{\sigma_H}} df \right]^{\frac{\sigma_H}{\sigma_H - 1}}$$

To solve for $\mu_{H,t}$ it is enough to substitute (B9) into (B8):

(B10) $$\mu_{H,t} = \left[\left(\frac{1}{n}\right) \int_0^n P_{H,t}(f)^{1-\sigma_H} \; df \right]^{\frac{1}{1-\sigma_H}} = P_{H,t}$$

So that the individual demand for the unique good $C_{H,t}(f)$ can be written as:

(B11) $$C_{H,t}(f) = \frac{1}{n}\left(\frac{P_{H,t}(f)}{P_{H,t}}\right)^{-\sigma_H} C_{H,t}$$

Now substituting (B4a) into (B11) produces the equation (2.12) in the main text.

Individual demand for the unique good $C_{F,t}(f)$ can be obtained in the similar manner, i.e. by solving the following household's minimum expenditure problem:

(B12)
$$\min_{C_{F,t}} \int_n^1 P_F(f) C_F(f) df$$
$$s.t.\; C_{F,t} \equiv \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma_F}} \int_n^1 C_{F,t}(f)^{\frac{\sigma_F - 1}{\sigma_F}} df \right]^{\frac{\sigma_F}{\sigma_F - 1}}$$

$$L = \int_n^1 P_F(f) C_F(f) df \quad + \mu_{F,t}\left[C_{F,t} - \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma_F}} \int_n^1 C_{F,t}(f)^{\frac{\sigma_F - 1}{\sigma_F}} df \right]^{\frac{\sigma_F}{\sigma_F - 1}} \right]$$

So that:

(B13) $$C_{F,t}(f) = \frac{1}{1-n}\left(\frac{P_{F,t}(f)}{P_{F,t}}\right)^{-\sigma_F} C_{F,t}$$

Now substituting (B3a) into (B13) produces the equation (2.13) in the main text.

ANNEX B.2. HOME BIAS

Preferences in home and foreign country can be respectively described as:

(B14) $$C_t = \left[\lambda^{\frac{1}{\phi}} C_{H,t}^{\frac{\phi-1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}} C_{F,t}^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}$$

(B15) $$C_t^* = \left[(\lambda^*)^{\frac{1}{\phi}} C_{H,t}^{*\,\frac{\phi-1}{\phi}} + (1-\lambda^*)^{\frac{1}{\phi}} C_{F,t}^{*\,\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}$$

where λ and $(1-\lambda^*)$ stand for home bias in the home and foreign economy, respectively.

Recall that demand functions for home and foreign goods are represented by (B3a) and (B4a). The demand functions for Home export can be derived analogously so that:

(B16) $$C_{H,t}^* = \lambda^* \left(\frac{P_{H,t}^*}{P_t^*} \right)^{-\phi} C_t^*$$

(B17) $$C_{F,t}^* = (1-\lambda^*) \left(\frac{P_{F,t}^*}{P_t^*} \right)^{-\phi} C_t^*$$

Now, dividing (B4a) by (B3a) and (B16) by (B17) gives:

(B18) $$\frac{C_{H,t}}{C_{F,t}} = \frac{\lambda}{1-\lambda} \left(\frac{P_{H,t}}{P_{F,t}} \right)^{-\phi}$$

(B19) $$\frac{C_{H,t}^*}{C_{F,t}^*} = \frac{\lambda^*}{1-\lambda^*} \left(\frac{P_{H,t}^*}{P_{F,t}^*} \right)^{-\phi}$$

It is obvious that home bias in foreign preferences requires:

(B20) $(1-\lambda^{*}) > (1-\lambda)$ (or that $\lambda > \lambda^{*}$)

Now, given that

(B21) $1 - \lambda = (1 - n) * \omega, \; \lambda = 1 - (1 - n) * \omega$

(B22) $\lambda^{*} = n\omega^{*}, 1 - \lambda^{*} = 1 - n\omega^{*}$

where ω and ω^{*} stand for the degree of home and foreign country openness.

and using (B20), it can be shown that:

(B23) $1-\omega > n(\omega^{*}-\omega)$

(or that $1 - (1 - n) * \omega > n\omega^{*}$), which means that for the home bias to occur, it must be also that $\omega < 1$. In a limiting case when $n \rightarrow 0$, $1 - \lambda = \omega, \; \lambda = 1 - \omega,$ and $\lambda^{*} = 0, \; 1\text{-}\lambda^{*} = 1$ (i.e. home does not matter from the perspective of the foreign economy).

ANNEX B.3. MARGINAL COST DERIVATIONS

In order to derive the expression for the marginal cost $MC_{H,t}$, the following cost minimisation problem is solved:

(B24)
$$\min_{K_t, N_t} TC_t = R_t^K K_{t-1} + W_t N_t$$
$$s.t \quad Y_{H,t} = \chi^{I-1} A_t (K_{t-1})^{\alpha} \; (N_t)^{1-\alpha}$$

where TC_t stands for the total cost of the firm with the Cobb-Douglas production function.

The values of K_{t-1} and N_t that minimize this cost respectively are:

(B23) $$K_{t-1} = \frac{Y_{H,t}}{\chi_t^{\,t-1} A_t} \left(\frac{W_t}{R_t^K} \frac{\alpha}{1-\alpha} \right)^{1-\alpha}$$

(B24) $$N_t = \frac{Y_{H,t}}{\chi_t^{t-1} A_t} \left(\frac{W_t}{R_t^K} \frac{\alpha}{1-\alpha} \right)^{-\alpha}$$

From the above, the following ratio can be obtained:

(B25) $$\frac{W_t}{R_t^K} = \frac{1-\alpha}{\alpha} \frac{K_{t-1}}{N_t}$$

Now the total cost can be expressed in terms of $Y_{H,t}$:

$$TC_t = R_t^K K_{t-1} + W_t N_t =$$

(B26) $$= \frac{Y_{H,t}}{\chi_t^{t-1} A_t} \left\{ R_t^K \left(\frac{W_t}{R_t^K} \frac{1-\alpha}{\alpha} \right)^{1-\alpha} + W_t \left(\frac{W_t}{R_t^K} \frac{1-\alpha}{\alpha} \right)^{-\alpha} \right\} =$$

$$= \frac{Y_{H,t}}{\chi_t^{t-1} A_t} \left(R_t^K \right)^{\alpha} W_t^{1-\alpha} \left\{ \frac{1}{\alpha^{\alpha} (1-\alpha)^{1-\alpha}} \right\}$$

So nominal $MC_{H,t}$ equals:

(B27) $$MC_{H,t} = \frac{\delta TC_t}{\delta Y_{H,t}} = \frac{1}{\alpha^{\alpha} (1-\alpha)^{1-\alpha}} \frac{\left(R_t^K \right)^{\alpha} W_t^{1-\alpha}}{\chi_t^{t-1} A_t}$$

To get real marginal cost $mc_{H,t}$, nominal $MC_{H,t}$ is divided by P_t.

(B28) $$mc_{H,t} = \frac{1}{\alpha^{\alpha} (1-\alpha)^{1-\alpha}} \frac{\left(r_t^K \right)^{\alpha} w_t^{1-\alpha}}{\chi_t^{t-1} A_t}$$

ANNEX B.4. CALIBRATED PARAMETER VALUES

Table B.4. 1 Baseline parameter values

Description	Symbol	Value
Intertemporal discount factor	β	0.99
Coefficient of risk aversion	ρ	5
Frisch elasticity of labour supply	η	0.3
Elasticity of substitution between H and F goods	ϕ	2
Price elasticity of demand in the H sector	σ	6
Steady-state revenue tax	τ	0.1
Mark-up	μ	1.33
Home bias	λ	0.7
Degree of openness	ω	0.3
Capital share in the H sector	α	0.35
Steady-state capital depreciation rate	δ	0.025
Adjustment cost in changing capital stock	ν	16
Impact of quality changes on marginal cost of the firm	ι	0.1

Source: Author's calibration

CHAPTER 3

EXPLAINING REAL EXCHANGE RATE MOVEMENTS IN NMSS OF THE EUROPEAN UNION – AN EXPANDED SOE MODEL

3.1 INTRODUCTION

The task of this chapter is to improve the overall performance of the SOE model of real exchange rate determinants for the NMSs of the EU put forward in Chapter 2. Special attention is drawn to matching the empirical volatilities of international variables, and the possible channels of real exchange rate appreciation observed in the NMSs.

First, given the mixed success of the one-sector model presented in Chapter 2 in replicating RER volatility, the nontradable sector is added to the model economy. This allows for testing of the degree to which RER movements in the NMSs can be accounted for by the deviations of relative price of nontradable goods between these countries and the eurozone. Although the empirical literature on the HBS effect in the NMSs stresses that this effect alone is not enough to explain the recorded real appreciation in the NMSs (see Chapter 2 for details), most papers investigating this effect do find evidence for its positive contribution to the RER appreciation observed in these countries. Also, as will be shown in the next section, the limited relevance of the HBS effect for the NMSs may be related to measurement problem. Furthermore, testing for the relevance of the nontradable sector for the RER movements is justified by newer research findings, which question Engel's (1999) conclusion that the nontradable sector is insignificant in explaining real exchange rate movements, and may also add to its volatility (see, for example, Selaive and Tuesta (2006)). For example, Burstein et al. (2005), point out that Engel's measures do not separate the distribution cost component of tradable good prices. When these authors adjust traded good prices for a tradable component, they find that around 50 percent of

RER movements should be attributable to the movements in the relative price of nontraded goods (see also Betts and Kehoe (2006)[90])[91].

Second, the complete market assumption is revoked – i.e. in this modified model risk-sharing is incomplete. As argued by Theonissen (2006) in his two-country intertemporal optimising model, incomplete financial markets are a necessary condition for the terms-of-trade and the real exchange rate to display realistic levels of volatility[92]. Furthermore, a model with incomplete financial markets allows for another channel of possible real exchange rate fluctuations, namely the impact of international payments on the real exchange rate[93]. More precisely, in the absence of a complete set of state-contingent claims, shocks between countries can also be transmitted via the current account. A shock that results, for instance, in a current account deficit redistributes wealth from the country experiencing this deficit to the surplus economy. This international transfer of resources, called the wealth effect, can of course affect relative prices and thus the real exchange rate. There are various ways in which wealth effects can operate in a model with incomplete markets. For example, as discussed in Benigno and Thoenissen (2006), following a positive supply-side shock to the home economy's traded goods sector, Home becomes richer and demands more goods of all types. As a risk-sharing mechanism, the terms-of-trade depreciate, improving the purchasing power of foreign consumers. However, because risk-sharing is incomplete, the terms-of-trade do not have to depreciate as much as they would have if a full set of state contingent claims were available – i.e. with less risk-sharing, the required transfer of purchasing power from Home to Foreign, and thus the required improvement of the trade balance, is smaller. Thus, in a two-sector model with incomplete markets, the contribution of terms-of-trade to the real exchange rate depreciation in response to tradable productivity

[90] Specifically, Betts and Kehoe (2006) find that the measured relation between the bilateral RER and the relative price of non-traded to traded goods is strong on average.
[91] Also, recall that the evidence of the contribution of non-tradable prices to the inflation differentials in the EMU Member States is mixed (see Andrés et al. (2006) and Altissimo et al. (2005) quoted in the introduction to this thesis).
[92] As in Chapter 2, throughout this chapter terms-of-trade is defined as the relative price of domestic imports in terms of exports.
[93] Additionally, as shown in Chapter 2, the complete market assumption implies unitary (or close to unitary) correlation between relative consumption and the RER. This implication is however rejected by the data, where this correlation is either low or negative – the so-called 'Backus-Smith puzzle' (see, Chari et al. (2002), Benigno and Thoenissen (2006) among others).

improvements should be smaller. Additionally, with incomplete markets and in the presence of nontradable goods, it is also possible to look at the redistribution of wealth associated with another transfer effect – namely, the impact of the wealth effect on labour supply, which should work similarly to the HBS effect and thus lead to RER appreciation (Lane and Milesi-Ferretti (2000), Selaive and Tuesta (2003, 2006))[94]. As before, a positive productivity shock to the tradable sector increases the relative price of imported goods, which makes Home consumers substitute away from imported towards domestic tradable goods. Other things being equal, this improves the current account (i.e. an accumulation of net foreign assets is observed). This transfer of resources to Home exerts a positive wealth effect, which in the presence of nontradable goods should reduce the labour supply to this sector, thus increasing the relative price of nontradables and inducing a real exchange rate appreciation.

Unfortunately, even if markets are incomplete, standard two-sector DSGE models fail to explain a significant divergence of domestic relative prices and real exchange rate appreciation (Benigno and Thoenissen (2003) and Vilagi (2005) among others). This is because, in this type of model, a positive productivity shock typically causes a terms-of-trade depreciation, which offsets an appreciation caused by the HBS or positive wealth effects. For instance, Vilagi (2005) argues that the HBS-like effect can only be achieved in NOEM models when pricing-to-market is incorporated into the model. Therefore, in the third modification to the model of Chapter 2, here, a distribution sector (a form of pricing-to-market) is introduced, a feature which breaks the LOOP in the tradable sector[95]. Moreover, Betts and Kehoe (2006) do find significant bilateral deviations from the LOOP for baskets of goods that are traded, and they do confirm that these deviations play a large role in real exchange rate fluctuations. Therefore it is important not only to develop a two-sector model, but also to include a mechanism that allows for breaking from the LOOP for

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[94] For simplicity, the model does not provide for the possibility of a steady-state net foreign asset position which is different from zero.

[95] The empirical failure of the LOOP due to the price discrimination is reviewed in Rogoff (1996) and also documented, for example, in Goldberg and Knetter (1997). Recall that in the model proposed in Chapter 2 even though PPP did not hold due to the presence of home bias in consumption, for simplicity, the LOOP was maintained.

individual tradable commodities. Introducing distribution trade costs in the model is also relevant because of the findings of Burstein et al. (2005) described above.

How does the introduction of the distribution sector help induce RER appreciation in response to a positive productivity shock? As shown in Corsetti et al. (2008), in the two-country, two-sector, symmetric DSGE model with incomplete markets, both the RER and terms-of-trade can improve, provided that the economy has a sufficiently high degree of home bias in absorption (another way through which the transfer effect can operate) and a sufficiently low trade elasticity, where this low trade elasticity arises from the presence of distribution trade costs[96]. This is because in the case when Home has a preference for domestic tradables, a positive productivity shock in the domestic tradable sector creates a negative income effect (a terms-of-trade depreciation reduces relative home wealth) implying a decline in global demand for domestic goods. However, since domestic households are the main consumers of domestic tradable goods, their wealth cannot drop too much, i.e. the relative price of home tradable goods must go up to generate enough demand to clear the global market[97]. According to Corsetti et al. (2008), this can happen if the demand effect arising from the presence of home bias is reinforced by a sufficiently low elasticity of substitution between Home and Foreign traded goods (i.e., they set the implied trade elasticity to 0.5). This is because low trade elasticity is associated with high volatility of international prices, which brings about strong wealth effects from price changes. Moreover, as stressed by these authors and demonstrated in Heathcote and Perri (2002), low trade elasticity contributes to the increased volatility of the real exchange rate, helping to match the moments of the data.

In summary, in contrast to the basic SOE-DSGE model of Chapter 2, the model proposed in this chapter is characterised by a nontradable sector, incomplete financial markets and distributive trade costs. Otherwise the model presented in this

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[96] Derivations of equation 16 of Corsetti et al. (2008), which shows the impact of distribution services on the elasticity of demand can be found in Annex C.4.

[97] Notice that the presence of home bias is important for two reasons. First, home bias ensures that changes in the price of domestically produced traded goods affect the relative price of traded goods. Otherwise, if the weights were the same, the relative price of traded goods would not change as the domestic and foreign aggregate price indices for traded goods would increase by the same amount. Second, it generates additional demand for domestically produced goods, which results in their higher prices to clear the market.

chapter retains the characteristics of the basic model of Chapter 2. Namely, given the importance of the demand effect arising from the presence of home bias, and its contribution to terms-of-trade (and thus real exchange rate) improvements in response to the positive productivity shock described above, the model presented in this chapter continues to assume that Home and Foreign consumers prefer to consume domestically produced tradable goods[98]. It also maintains the exogenous quality factor, given that quality improvements are well documented in the NMSs of the EU (see Chapter 2), and because a positive quality shock in the basic version of the model did trigger the appreciation of the real exchange rate. Also, as the variance decomposition conducted in the previous chapter showed, quality improvements were not insignificant in explaining RER fluctuations. However, because the extended model put forward below is a two-sector model, and because quality improvements are more likely to occur in the tradable sector (see the discussion on the developments in terms-of-trade and export unit values in Poland in Chapter 2), in this chapter, quality innovations are placed in this sector.

The model presented in this chapter, calibrated to the Polish economy, shows that positive productivity shocks indeed generate real exchange appreciation consistent with the HBS theory and positive wealth effects[99]. This appreciation is possible despite the country's terms-of-trade deterioration. The obtained result is in contrast to standard two-sector DSGE models, which have difficulties in generating the RER appreciation related to a positive productivity shock. Even if recent papers by Selaive and Tuesta (2006) or Corsetti et al. (2008), do show that such appreciation is possible in the two-country symmetric model, to the author's best knowledge there are no models which show this outcome in the small open economy IRBC framework, which is the contribution of this paper[100]. The model further shows that such appreciation depends on the value of elasticity of substitution between domestic

[98] The role of home bias in a two-sector model of the UK equilibrium exchange rate was investigated by Benigno and Thoenissen (2003). Similar to the results of simulations run on the one-sector model of Chapter 2, in Benigno and Thoenissen, the presence of home bias was not enough to generate strong demand effects which would trigger terms-of-trade improvements.

[99] Note that for the HBS effect to hold various assumptions must be satisfied. For example, LOOP must hold, sectoral wages must equalize, domestic and foreign tradable goods should be close substitutes, etc. Unless these are met, what is often called the HBS effect should be understood as the impact of a positive productivity shock in the tradable sector on the internal real exchange rate.

[100] Unlike here, in both papers by Corsetti et al. (2008) and by Selaive and Tuesta (2006), RER appreciation is combined with terms-of-trade improvement.

and foreign tradable goods as well as the value of the parameter governing bond holding costs. The value of the parameter governing bond holding costs also determines whether the RER appreciates or depreciates in response to the positive quality shock. This confirms the importance of the current account channel in the real exchange rate modelling. The expanded model is also able to deliver a good match in terms of RER volatility and persistence of the Polish RER without recourse to nominal rigidities, monetary shocks or extremely low values of trade elasticity. Although the model shows that positive tradable productivity and quality shocks could be consistent with an appreciation of the Polish zloty, the results of the variance analysis run counter to the view that either productivity or quality improvements in the tradable sector lead to inflation differentials between New and Old Member States. The model suggests that tradable productivity, and to lesser extent quality improvements are only important in explaining movements of terms-of-trade, i.e. the shocks originating in the tradable sector are not relevant for the movements of the Polish real exchange rate. Instead, asymmetric shocks originating in the nontradable sector are of importance.

The rest of the paper proceeds as follows: Section 3.2 discusses and evaluates the additional possible sources of real exchange rate movements in a typical NMS of the EU represented by Poland. Section 3.3 sets out the theoretical model. Section 3.4 presents the parameterization of the model, evaluates the model results and its ability to match the moments of the observed data. Section 3.5 concludes.

3.2 POSSIBLE SOURCES OF REAL EXCHNAGE RATE APPRECIATION IN THE NMSs – MODEL BUILDING BLOCKS

The aim of this section is to empirically verify the importance of the two additional proposed building blocks of the SOE DSGE model of the real exchange rate determinants in a typical NMS of the European Union, represented by Poland.

As a first step, and in light of the existing controversy as to what extent nontradable prices influence the real exchange rate movements in the NMSs, an attempt is made below to establish the degree to which RER fluctuations can be explained by movements in the relative price of nontraded goods in Poland. As a second step, the possibility is investigated of introducing a distribution sector in the model, through an evaluation of the role of distribution trade costs in breaking the LOOP in Poland.

3.2.1 Nontradable goods

To establish the extent to which the relative price of nontraded goods can impact real exchange rate movements, an 'Engel-type' exercise is performed, where three different price indices for tradable (T) and nontradable (NT) sectors are considered (see Annex C.1 for details)[101]. Then, the Mean Squared Error (MSE) of the change in the RER is used as a measure of volatility (an uncentered measure of volatility). A measure is made of the how much of the MSE of changes in the RER is attributable to changes in the nontradable component of RER (RER_t^{REL}):

(3.1)

$$MSE_t\left(RER_t - RER_{t-n}\right) = \frac{MSE_t\left(RER_t^{REL} - RER_{t-n}^{REL}\right)}{MSE_t\left(RER_t^{REL} - RER_{t-n}^{REL}\right) + MSE_t\left(RER_t^{T} - RER_{t-n}^{T}\right)}$$

where RER_t^{REL} is the weighted difference of the log of the relative price of nontraded to traded goods in each country[102].

Graph 1 in Figure 3.1 below presents a decomposition of the Polish real exchange rate into tradable and nontradable components where the price indices were calculated from the different sub-categories of the Harmonised Index of Consumer Prices (HICP) with the weights proposed by Engel (1999). Based on this decomposition, the importance of nontradable prices in overall real exchange rate fluctuations seem to be quite low, although increasing in time (around 10 per cent). Graph 2, where tradable prices were approximated by the PPI index, and nontradable prices approximated by the HICP index, points to the higher importance of

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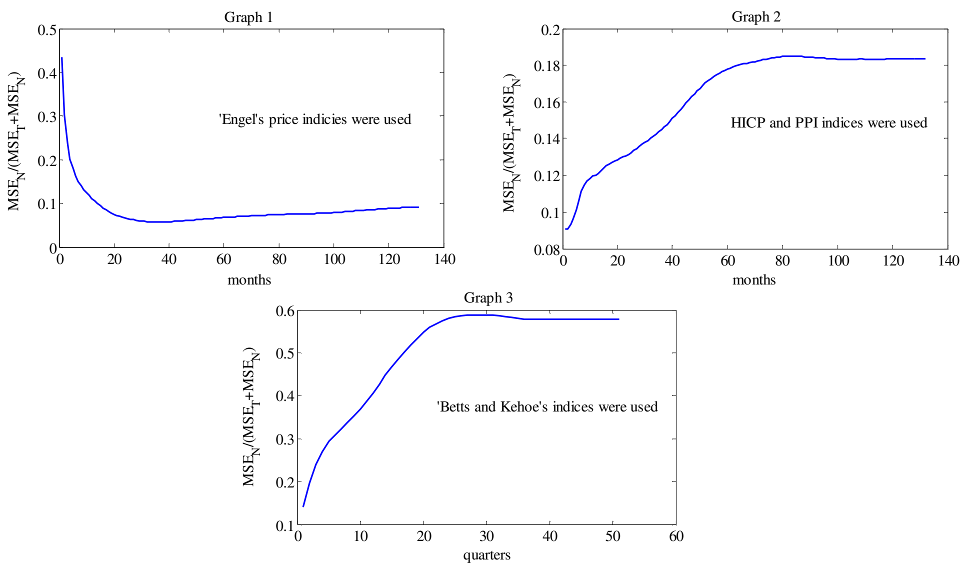
[101] Due to data constraints, quarterly data is used in constructing the tradable and non-tradable price indices for Graph 3, Figure 3.1, while monthly data is used in the construction of the price indices for Graphs 1 and 2, Figure 3.1.

[102] Betts and Kehoe (2006) call the non-tradable component RER^{NT}. For differences between the two see Appendix 1.

nontradable prices in the RER movements (around 20 per cent). Finally, Graph 3 presents the decomposition of the real exchange rate using price indices proposed by Betts and Kehoe (2006)[103]. Here the importance of the nontradable component appears to be mostly significant and equals around 60 per cent.

Figure 3.1. Decomposition of the Movements of Polish Real Exchange Rate



Source: Author's calculation based on the Eurostat data (the horizontal axis in Graph 1 and 2 measures time in months, in Graph 3 in quarters). The vertical axis measures how much of the MSE of changes in the RER is attributable to changes in the nontradable component of RER.

Clearly, the importance of nontradable prices in explaining real exchange rate fluctuations in Poland varies depending on the construction of price indices in both sectors. This is because the correct split between the tradable and nontradable sectors is extremely difficult to determine, and subject to measurement problem (related to the availability of disaggregated data and classification of tradable and nontradable goods), and because of the presence of regulated prices in the NMSs (see Błaszkiewicz et al. (2005) for more details on the issue). For example, the share of tradable goods in CPI indices is typically larger than in other price indices as it

[103] More precisely, Betts and Kehoe (2006) use gross output by sector data. Here, due to data availability, sectoral Gross Value Added is used instead.

excludes a large part of GDP consumed by the government sector (Ravenna and Natalucci (2007)).

In the calculations above, the share of the tradable price in the Polish HICP index constitutes 70 percent. This is a very high value, especially when compared with the share of 30 percent based on Gross Value Added deflators used for the Betts and Kehoe's decomposition (and also when compared with openness of the Polish economy, which is around 30 percent (see Section 2.4.1)). Moreover, the assumption made by Engel, that all goods are tradable, is questionable as some goods sub-categories do include services and are subject to regulated prices. Therefore, additional analysis is necessary. As pointed out in Engel (1999) and evaluated in more depth in Betts and Kehoe (2006), the RER and the relative nontradable price series (i.e. RER_t and RER_t^{REL} series in Annex C.1) should be uncorrelated if nontradable prices were not to matter for the real exchange rate movements.

Table 3.2.1 presents the correlations and standard deviations of the RER_t and RER_t^{REL} series. The results are in contrast with Engel's predictions: irrespective of the price indices used, the correlation between RER_t and RER_t^{REL} is not insignificant.

Table 3.2.1 Basic statistics for RER_t and RER_t^{REL} series

	CORR_L	STD_L	CORR_D	STD_D
ENGEL	0.64	0.25	0.66	0.65
PPI_HICP	0.82	0.27	0.58	0.28
BETTS AND KEHOE	0.63	0.56	0.30	0.68

Note: Author's calculations based on the Eurostat data. Columns CORR_L and CORR_D present correlations between the respective pairs of series: (RER_t, RER_t^{REL}) and (ΔRER_t, ΔRER_t^{REL}). Columns STD_L and STD_D present relative standard deviations between RER_t^{REL} and RER_t and ΔRER_t^{REL} and ΔRER_t .

In summary, the results above show that in contrast to Engel's (1999) findings for the US/Japan real exchange rate, nontradable prices do contribute to fluctuations of the Polish real exchange rate, even if tradable prices also matter. Therefore, in order to build a model of real exchange rate determination which would also match data for the Polish economy, the relative internal exchange rate movements between Poland and the eurozone should be taken into account, in addition to deviations from the LOOP.

3.2.2 Distribution Services

A body of evidence suggests that final goods contain a substantial nontraded component, which accounts for a large fraction of deviations from the LOOP in developed countries (Burstein et al. (2003), McDonald and Ricci (2001), Corsetti and Dedola, (2005)). Therefore, Corsetti et al. (2008) propose adding a distribution sector to the standard DSGE model. They further demonstrate that this feature not only contributes to breaking the LOOP, but also – by lowering the elasticity of substitution between home and foreign tradable goods[104] – helps generate the terms-of-trade and real exchange rate improvements in response to a positive productivity shock observed in the US data. Because the real exchange rate appreciation and terms-of-trade improvements are also observed in the NMSs, and because there is empirical evidence that this facts could be related to productivity improvements in these countries (see Annex A.1, Figure A.1.1 in Chapter 1 and Figure 2.1 in Chapter 2), following Corsetti et al. (2008), the distribution sector is also included in the SOE model proposed for Poland.

Unfortunately, there are virtually no empirical studies showing the significance of this sector in generating deviations from the LOOP in Poland. The only study that addresses the issue in the context of the NMSs is that of MacDonald and Wojcik's (2004), which shows that distribution trade costs in Estonia and Slovenia play an important role in real exchange rate dynamics in these countries (over and above the HBS effect). The authors report that distribution services in Estonia and Slovenia account for 15 and 12 per cent of total value added, respectively[105].

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[104] See Annex C.4 for the exposition of the mechanism at work.
[105] Although they do not explain the definition of the distribution sector that they use.

Given the lack of other evidence, the share of the distribution sector in the Polish value added is calculated to estimate the potential role of distribution services in explaining real exchange rate movements in Poland. Based on data from the Polish Ministry of Finance, the share of distribution services (classified as transport, storage and communication) in the Polish value added in 2006 was around 7 per cent. However, if wholesale and retail trade are included in distribution services (the standard classification), this jumps to 26 per cent (i.e. wholesale and retail trade constitutes 19 per cent of the domestic value added). This number is lower than the 32 per cent shown by Goldberg and Campa (2006) for Poland for 2000[106].

In summary, the SOE DSGE model proposed in this chapter will take into account the following factors/channels, which from the empirical point of view seem to be important determinants of the RER in Poland and could also contribute to its appreciation in response to tradable productivity improvements: internal real exchange rate channel, the distribution services channel (pricing-to-market), and the impact of international payments on the RER. This is in addition to the terms-of-trade channel of the real exchange rate determination proposed in Chapter 2 (i.e. quality adjustments and home bias).

An observed in the NMSs RER appreciation could, of course, result from a number of other factors, which are not included in this model. For example, a RER appreciation could arise in response to a risk premium shock and the associated increased capital inflow to the NMSs (see for example von Hagen and Siedschlag (2008)). This additional transfer of resources from abroad would have to be met by increased domestic absorption. If increased spending occurred in the nontradable sector, the price of these goods would have to increase, causing real appreciation of the domestic exchange rate (if it fallen on tradables, it could be absorbed by a trade deficit) (see, for example, Calvo et al. (1993)). This outcome is not unlikely, given the favourable investment opportunities, including 'convergence play', in these countries. This has already been observed in credit booms, and where increased

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[106] In Goldberg and Campa's analysis the share of distribution services in the Polish value added is the lowest out of 21 analysed economies. Goldberg and Campa's results for industrial countries are in line with those recorded by Burstein et al. (2003) (around 50 percent), but higher than the average level of 15 percent reported by McDonald and Ricci (2001).

growth of real money exceeds the real GDP growth (see von Hagen and Siedschlag (2008))[107]. RER appreciation could also arise from the nominal appreciation observed in the NMSs. However, as shown in Chapter 1, in almost all NMSs, real factors are responsible for movements of real exchange rates.

3.3 THE SOE / DSGE / IRBC MODEL – A NON-TECHNICAL SUMMARY

The core analytical framework developed in this chapter is an optimizing, two-sector (tradable and nontradable), small open economy model along the lines of Benigno and Thoenissen (2003) or Natalucci and Ravenna (2002, 2007).

Following Benigno and Thoenissen (2003), but in contrast to Natalucci and Ravenna (2002, 2007), in the model the assumption regarding perfect competition and homogeneity of goods in the traded sector is lifted. This provides for the role for terms-of-trade in movements of the real exchange rate in a typical NMS of the EU (i.e., the prices for the tradable sector are no longer exogenously given and are affected by differentiated products, home bias and distribution costs). Modifying the aforementioned papers, the model introduces a perfectly competitive distribution sector (in accordance with Burstein et al. (2003), Corsetti and Dedola (2005), Corsetti et al. (2008), and Selaive and Tuesta (2003, 2006) and the evidence provided in Section 3.2.2), which together with home bias in consumption minimises the degree of the exchange rate pass-through.

Similar to the model of Chapter 2, but unlike the aforementioned papers, for the reasons discussed in Chapter 2, the model does not include nominal rigidities and the potential role of monetary policy and/or money in economic fluctuations. However neither the LOOP nor purchasing power parity (PPP) hold in the model. On the one

[107] 'Convergence play', a combination of real appreciation and declining long-term interest rates due to falling inflationary expectations and country-risk premiums, makes these economies even more attractive for short-term capital inflows and portfolio investment. For example, in Italy, Spain, and Portugal in the late 1980s and early 1990s, convergence play exacerbated domestic demand for non-tradables, leading to economic overheating and inflationary pressures (due to limited supply). With a fixed exchange rate, increases in price levels leads to a real appreciation of the domestic currency. With a floating rate, the central bank can do more to suppress inflationary pressures and allow the nominal exchange rate to appreciate (see von Hagen and Siedschlag (2008) for details).

hand, the existence of home bias together with the presence of a nontradable good violates PPP. On the other hand, market segmentation caused by distribution services drives a wedge between producer and consumer prices and thus violates the LOOP. As both traded and nontraded sectors are monopolistically competitive, the LOOP is also broken at the producer level. As previously, the model focuses on the SOE case, which means that home bias in consumption depends on the relative size of the economy and its degree of openness (see Sutherland (2002) or de Paoli (2004) quoted in Chapter 2 and Annex B.2 for more details).

The model also features incomplete risk-sharing, which makes it possible to account for wealth effects[108]. However, in the absence of a complete set of state-contingent claims, the associated redistribution of assets affects the steady-state of the model, causing it to change in response to temporary shocks, which means that the steady-state can become nonstationary. In order to ensure stationarity of the model, in addition to an endogenously well defined steady-state, the convex cost of undertaking positions in the international asset markets is introduced[109]. This means of inducing stationarity into small open economy models with incomplete markets was discussed at length by Schmitt-Grohe and Uribe (2003) and can be found in the work of Benigno (2001) or Kollmann (2002) [110].

Because intermediate goods are the largest component of imports in the NMSs, following Natalucci and Ravenna (2002, 2007), the production function proposed in the model is the composite of domestic value added and imported goods. On the nontradable sector side, imported goods enter the nontradable sector production function through capital accumulation (investment goods are the aggregate of nontradable, home and foreign goods).

The model is then calibrated to a typical NMS, represented by Poland. Numerical methods are used to solve the model (see the discussion in Chapter 2).

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108 The existence of wealth effects means that changes in a consumer's wealth cause changes in the amounts and composition of his consumption.

109 See footnote 125 and 126 for more details.

110 Nataluci and Ravenna (2003, 2007) preferred way of achieving stationarity of the model is an introduction of a debt elastic interest rate premium. However, as shown by Lubik (2007), this approach can imply non-existence of the rational expectations equilibrium.

3.4 THE SOE / DSGE / IRBC MODEL – TECHNICAL DETAILS

For the model developed below, assumptions about the distribution of infinitely lived agents (in the small and large economy), the size of the country, migration, and households' consumption of goods' varieties remain the same as in Chapter 2. However, now, in each country there are two sectors producing differentiated tradable and nontradable goods. The tradable home good is distributed along the continuum $h \in [0,1)$, tradable foreign good along $f \in (1,n]$ and the nontradable good along $nt \in [0,1)$. Moreover, as mentioned, this time households do not have access to contingent securities markets against which they can insure at the domestic as well as the international level, i.e., the markets are incomplete. Each firm at home and abroad produces one of the varieties of the domestic and foreign goods, respectively, so that differentiated goods (varieties) in two countries are also indexed by h, f, and nt.

3.4.1 Households

The utility function of a household *s* is the same as in Chapter 2. However, given the multi-sector set-up, labour N_t^s is supplied to the H and NT sectors:

$$N_t^s = N_{H,t}^s + N_{NT,t}^s \tag{3.2}$$

The time endowment is normalised to 1 (i.e., the sum of leisure and the number of hours work is normalized to one). As previously, it is assumed that labour N_t^s is mobile among sectors in each country and immobile internationally.

Consumption and Price Indices

A representative household *s* can choose between three types of goods: H, NT and F (home tradable and nontradable and foreign tradable, respectively). The composite good C_t^s is aggregated from T and NT goods. Household's *s* preferences over consumption goods are defined as follows:

$$(3.3) \qquad C_t^s = \left[(\gamma)^{\frac{1}{\varepsilon}} C_{T,t}^{s\ \frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)^{\frac{1}{\varepsilon}} C_{NT,t}^{s\ \frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

where $0<\varepsilon<1$ and $\varepsilon>1$ is the elasticity of substitution between tradable and nontradable consumption good[111], $0 \le \gamma \le 1$ is the share of traded goods in consumption. Traded consumption good $C_{T,t}^s$ is a composite of the domestically produced traded good H and foreign produced traded good F:

$$(3.4) \qquad C_{T,t}^s = \left[(1-\omega)^{\frac{1}{\phi}} C_{H,t}^{s\ \frac{\phi-1}{\phi}} + (\omega)^{\frac{1}{\phi}} C_{F,t}^{s\ \frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}$$

where, as in Chapter 2, $0<\phi<1$ and $\phi>1$ is the elasticity of substitution between home and foreign tradable goods[112], and where $\omega \in [0,1]$ represents the degree of openness of the small open economy (see Chapter 2 for the discussion on the relationship between the degree of openness and home bias in the SOE and Annex B.2 for derivations).

Consumption sub-indices are a continuum of differentiated home, nontradable and foreign goods (i.e., aggregates across brands in home, nontradable and foreign sectors ($C_{H,t}^s(h)$, $C_{NT,t}^s(nt)$, $C_{F,t}^s(f)$) within a country) and are defined as follows (for eq. (3.5) the analogous remark as in footnote 67 in Chapter 2 applies):

$$(3.5) \qquad C_{j,t}^s \equiv \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma_j}} \int_0^n C_{j,t}^s(j)^{\frac{\sigma_j-1}{\sigma_j}} dj \right]^{\frac{\sigma_j}{\sigma_j-1}} \qquad j = H, NT$$

[111] ε must be positive and greater than zero for tradable and non-tradable goods to be substitutes. The larger the ε, the more substitutable T and NT goods are. The Cobb-Douglas case (elasticity equal one) is not considered in this chapter as it does not allow for the discussion of substitutability of goods.

[112] For restrictions on ϕ see footnote 62.

(3.6) $$C_{F,t} \equiv \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\sigma_F}} \int_n^1 C_{f,t}(f)^{\frac{\sigma_F - 1}{\sigma_F}} df \right]^{\frac{\sigma_F - 1}{\sigma_F}}$$

where $\sigma_j, \sigma_F > 1$ represents the elasticity of substitution between differentiated goods (brands) in the tradable home and foreign sectors and is also the price elasticity of demand faced by each producer[113].

Given the above preferences and the fact that the final good aggregator is a zero-profit agent the following price index for the composite consumption good can be derived (see Annex C.2):

(3.7) $$P_t \equiv \left[\gamma P_{T,t}{}^{1-\varepsilon} + (1-\gamma) P_{NT,t}{}^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}$$

where $P_{T,t}$ and $P_{NT,t}$ are the prices of a composite Home and Foreign consumption good, respectively.

Similarly, for the tradable good:

(3.8) $$P_{T,t} \equiv \left[\lambda P_{H,t}{}^{1-\phi} + (1-\lambda) P_{F,t}{}^{1-\phi} \right]^{\frac{1}{1-\phi}}$$

where $P_{H,t}$ and $P_{F,t}$ are the prices of a composite Home and Foreign consumption good, respectively, and where, as in Chapter 2, λ represents home bias in the SOE.

Sectoral price sub-indices of H, NT and F goods are defined as follows[114]:

(3.9) $$P_{j,t} \equiv \left[\left(\frac{1}{n} \right) \int_0^n P_{j,t}(j)^{1-\sigma_j} dj \right]^{\frac{1}{1-\sigma_j}} \qquad j = H, NT$$

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[113] See footnote 68 in Chapter 2.

[114] It can be proved that in equation (3.9) $\lim_{n \to 0} P_{j,t} = e^{-\infty} = 0$ for $|\sigma_j| > 1$.

$$(3.10) \qquad P_{F,t} \equiv \left[\left(\frac{1}{n-1}\right)\int_n^1 P_{F,t}(f)^{1-\sigma_F}\, df\right]^{\frac{1}{1-\sigma_F}}$$

where $P_{H,t}(h)$, $P_{NT,t}(nt)$, $P_{F,t}(f)$ are prices of individual brands set by individual firms producing those brands in home, nontradable and foreign sectors.

Distribution trade costs

As discussed above, one of the features of the model is the existence of the competitive distribution sector, which delivers goods to consumers and is located between the intermediate and final producers. As in Burstein et al. (2003), and Corsetti and Dedola (2005) and Selaive and Tuesta (2006), it is assumed that bringing one unit of traded intermediate goods to consumers requires ζ units of a basket of differentiated *nontraded* goods[115] [116]:

$$(3.11) \qquad \zeta_t = \left[\left(\frac{1}{n}\right)^{\frac{1}{\sigma}} \int_0^n \zeta_t(nt)^{\frac{\sigma-1}{\sigma}}\, dnt\right]^{\frac{\sigma}{\sigma-1}}$$

The profit maximizatation problem for distribution sectors reads as follows:

$$(3.12) \qquad \max_{Y_{H,t}} P_{H,t}Y_{H,t} - P^P_{H,t}Y_{H,t} - \zeta P_{NT,t}Y_{H,t}$$

and yields the following profit maximization price:

$$(3.13) \qquad P_{H,t} = P^P_{H,t} + \zeta P_{NT,t}$$

where $P^P_{H,t}$ stands for the wholesale price of the domestic tradable good.

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[115] Note here that the Dixit-Stiglitz index above also applies to the consumption of differentiated non-traded goods. This means that in equilibrium, a basket of non-traded goods required to distribute tradable goods to consumers will have the same composition as a basket of non-tradable goods consumed by the representative domestic household (Corsetti and Dedola (2002)).

[116] See footnote 114.

An analogous equation can be derived for the price of the foreign good:

(3.14) $$P_{F,t} = P_{F,t}^{P} + \zeta P_{NT,t}$$

where $P_{F,t}^{P}$ stands for the wholesale price of the foreign tradable good.

Thus there is a difference between the producer (wholesale) and consumer (retail) prices[117]. The presence of distribution services in the tradable sector allows a representative firm to charge different prices at home and abroad, i.e., LOOP does not hold even at the producer level: $P_{H,t}^{P}(h) \neq P_{H,t}^{*P}(h)$ and $P_{F,t}^{P}(f) \neq P_{F,t}^{*P}(f)$ (as shown in (3.13) a tradable price contains a nontradable component in it, which, absent international competition, does not have to equalise, even after assuming the same share of distribution services in countries in question)[118]. Or to be more specific, in the production chain, distribution costs are realized before firms (retailers) combine each intermediate input variety into a composite traded good. The presence of distributive trade costs decreases the elasticity of demand (see Annex C.4). The domestic distribution margin μ^{D} is defined as a fraction of the final tradable price accounted for by distribution costs, and is equal to $\zeta P_{NT,t} / P_{i,t}$ (the share of the nontradable price in the price of the final home (foreign) tradable good), where $i = H, F$. For simplicity it is assumed that nontradable firms do not incur distribution costs (i.e. delivering nontradable goods to consumers does not require distribution services) and so:

(3.15) $$P_{NT,t}(nt) = P^{P}{}_{NT,t}(nt)$$

The real exchange rate is defined as:

[117] The same relationship applies to the price of the imported final good.
[118] To see differences in producer prices of the domestic tradable good sold at home and abroad see equations (3.50) and (3.51) as well as Annex C.5 for derivations. Expressions for producer prices of the foreign good sold at home and abroad can be derived analogously.

(3.16) $$Q_t = \frac{P_t^*}{P_t}$$

Individual demand functions for the representative consumer (household) can be obtained from the optimal allocation of expenditure across the NT, H and F goods (see Annex C.2):

(3.17) $$C_{NT,t}^S(nt) = \frac{1}{n}(1-\gamma)\left(\frac{P_{Nt,t}(nt)}{P_{NT,t}}\right)^{-\sigma}\left(\frac{P_{NT,t}}{P_t}\right)^{-\varepsilon} C_t^S$$

(3.18) $$C_{H,t}^S(h) = \frac{1}{n}\lambda\gamma\left(\frac{P_{H,t}(h)}{P_{H,t}}\right)^{-\sigma}\left(\frac{P_{H,t}}{P_{T,t}}\right)^{-\phi}\left(\frac{P_{T,t}}{P_t}\right)^{-\varepsilon} C_t^S$$

(3.19) $$C_{F,t}^S(f) = \frac{1}{1-n}(1-\lambda)\gamma\left(\frac{P_{F,t}(f)}{P_{F,t}}\right)^{-\sigma}\left(\frac{P_{F,t}}{P_{T,t}}\right)^{-\phi}\left(\frac{P_{T,t}}{P_t}\right)^{-\varepsilon} C_t^S$$

Similar to Benigno and Theonissen (2003), it can be shown that home bias arises when

(3.20) $$\frac{C_{H,t}^S}{C_{F,t}^S} > \frac{C_{H,t}^{S*}}{C_{F,t}^{S*}}$$

where:

(3.21) $$\frac{C_{H,t}^S}{C_{F,t}^S} = \frac{\lambda}{1-\lambda}\left(\frac{P_{H,t}}{P_{F,t}}\right)^{-\phi}$$

(3.22) $$\frac{C_{H,t}^{S*}}{C_{F,t}^{S*}} = \frac{\lambda^*}{1-\lambda^*}\left(\frac{P_{H,t}^{S*}}{P_{F,t}^{S*}}\right)^{-\phi}$$

and requires $\lambda > \lambda^*$ and $\omega < 1$[119].

[119] See also Annex B.2.

Investment

Households not only purchase final consumption goods, but also consume final investment goods. Investment, similar to consumption, requires tradable and nontradable inputs and is produced using the following CES technology:

$$I_t^s = \left[(\gamma)^{\frac{1}{\varepsilon}} I_{T,t}^{s\ \frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)^{\frac{1}{\varepsilon}} I_{NT,t}^{s\ \frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{3.23}$$

Tradable goods consist of H and F goods (foreign component of the capital good):

$$I_{T,t} = \left[(1-\omega)^{\frac{1}{\phi}} I_{H,t}^{\frac{\phi-1}{\phi}} + (\omega)^{\frac{1}{\phi}} I_{F,t}^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} \tag{3.24}$$

and

$$I_{j,t} \equiv \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma_j}} \int_0^n I_{j,t}(j)^{\frac{\sigma_j-1}{\sigma_j}} dj \right]^{\frac{\sigma_j}{\sigma_j-1}} \quad j = H, NT \text{ [120]} \tag{3.25}$$

$$I_{F,t} \equiv \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\sigma_F}} \int_n^1 I_{F,t}(f)^{\frac{\sigma_F-1}{\sigma_F}} df \right]^{\frac{\sigma_F}{\sigma_F-1}} \tag{3.26}$$

The elasticity of substitution between T and NT goods, ε, and the elasticity of substitution between H and F, ϕ, are the same as in the corresponding consumption indices. It is assumed that the composite investment good is produced by the same final good aggregator that is producing the composite consumption good. This assumption implies the same price indices for consumption and investment goods. Individual investment demand functions are analogous to those for consumption.

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[120] See footnote 114.

Household Capital Accumulation

Every firm rents capital services at the going rental rate $r^K_{j,t}$ ($j = H, NT$) from households. Households can increase the supply of capital services by accumulating more physical capital. They can choose to augment a composite investment good I_t (i.e., the aggregate investment expenditure for the whole economy) to the existing physical capital stocks by investing $I^S_{j,t}$ units of either the composite domestic tradable good or nontradable good[121]. Capital $K^S_{j,t-1}$ is pre-determined at the beginning of each period and thus is non-transferable between tradable and nontradables sectors. However, given that there are no constraints on investment, cross-sectional capital mobility is possible in subsequent periods. The stock of capital increases in accordance with the following law of motion (see, for example, Chari et al. (2002)):

$$K^s_{j,t} = (1-\delta)K^s_{j,t-1} + I^s_{j,t} - \frac{\nu}{2}\left(\frac{I^s_{j,t}}{K^s_{j,t-1}} - \delta\right)^2 K^s_{j,t-1} \qquad (3.27)$$

and $j = H, NT$

where ν is the adjustment cost in changing the capital stock employed by each intermediate good producer, and δ is the depreciation rate (common for both sectors). The quadratic function assumes that the adjustment is slow[122]. Because K^s_t is the end of period stock, the capital that will be available for use in period *t+1*.

Note that because investment good I^s_t is an aggregate of H, NT and F goods, foreign goods contribute to capital accumulation in the small open economy.

[121] The relation between equations (3.23)-(3.24) and (3.27) becomes clear once the economy wide constraint on investment is imposed (see market clearing condition (3.64)).
[122] See Footnote 70 in Chapter 2.

Resource constraint

As discussed, incomplete international asset markets are assumed. Households have access to two risk-free one-period real bonds. One bond is denominated in the domestic currency, the other in the foreign currency.

It is assumed that all households within the country have the same initial wealth, share earned profits in equal proportion, and own all domestic firms. This means that within the country all households face the same budget constraint (in units of domestic consumption good) [123]:

(3.28)

$$\frac{B_{H,t}}{(1+r_t)}+\frac{Q_t B_{F,t}}{(1+r_t^*)\Phi\left(Q_t B_{F,t}\right)}+C_t+I_{H,t}+I_{NT,t}\leq B_{H,t-1}+Q_t B_{F,t-1}+\frac{P_{H,t}^P}{P_t}w_{H,t}N_{H,t}$$

$$+\frac{P_{NT,t}}{P_t}w_{NT,t}N_{NT,t}+\frac{P_{H,t}^P}{P_t}r^K{}_{H,t}K_{H,t-1}+\frac{P_{NT,t}}{P_t}r^K{}_{NT,t}K_{NT,t-1}+\frac{\int_0^n \Pi_{H,t}(h)dh+\int_0^n \Pi_{NT,t}(nt)dnt}{n}+\frac{TR_t}{P_t}$$

where real household expenditures (normalized on P_t) are the left hand side of (3.28). $B_{H,t}$ and $B_{F,t}$ are the time *t* holdings of the risk-free real domestic and foreign bonds expressed in home consumption units, respectively. r_t and r_t^* represent domestic and foreign net real interest rates on these bonds, $I_{H,t}$ and $I_{NT,t}$ are households' investment decisions, C_t expresses consumption expenditure. Real household income sources are on the right hand side of (3.28). The remaining terms in the budget constraint express households' labour income from working in either the tradable or nontradable sector, $w_{H,t}N_{H,t}$ and $w_{NT,t}N_{NT,t}$ (where $N_{H,t}$ and $N_{NT,t}$ stand for hours worked in the tradable and nontradable sectors; $w_{H,t}=\frac{W_{H,t}}{P_{H,t}^P}$ and

[123] Therefore, in what follows, the superscript s was suppressed.

$w_{NT,t} = \frac{W_{NT,t}}{P_{NT,t}}$), nominal lump-sum government transfers, TR_t, real profits of a firm *i* received by the household *s* in period *t*, $\Pi_{H,t}$ and $\Pi_{NT,t}$. Finally, $r^K_{H,t} K_{H,t-1}$ and $r^K_{NT,t} K_{NT,t-1}$ depict household's rental income from renting capital services to goods-producing firms (similar to real wages, rental rates are also expressed in terms of sectoral prices)[124]. Consumers face no Ponzi game restriction. Transversality conditions apply.

Note that $\Phi(\bullet)$ is a function which depends on the real holdings of the foreign assets of the entire economy in terms of home goods[125]. It introduces a convex cost that allows for a stationary NFA position and a well defined steady-state (i.e., model's steady-state is independent of its initial conditions)[126]. It captures the costs of undertaking positions in the international asset markets (see Schmitt-Grohe and Uribe (2003), Selaive and Tuesta (2006)) [127].

In order to maximize utility, households choose a sequence of $\left\{C_t, I_{H,t}, I_{NT,t} K_{H,t}, K_{NT,t}, B_{H,t}, B_{F,t}, N_{H,t}, N_{NT,t}\right\}_{t=0}^{t=\infty}$ for all t=0…..∞, subject to the budget constraint and two equations describing capital accumulation in the tradable and nontradable sectors:

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[124] Notice that factor prices are valued at producer prices. This is because firms sell their output to distributors at this price, who in turn deliver goods to consumers at the consumer price. See also profit equations (3.48) and (3.60).

[125] $\Phi(\bullet) = e^{\frac{\upsilon}{2}\left(\bar{b}-b_t\right)}$, where υ is a constant, $b_t = Q_t B_{F,t}$, and $\bar{b}$ is the steady-state level of foreign assets. As in Benigno (2001), $\Phi(\bullet)$ is equal to one only when the NFA position is at its steady state level, i.e. $b_t = \bar{b}$, and is a differentiable decreasing function in the neighbourhood of zero.

[126] With incomplete markets, without these assumptions the wealth distribution in the deterministic steady state would be indeterminate and the first-order approximation around it would contain a unit root. In turn, this unit root would imply that the wealth distribution in the approximate solution to the stochastic economy does not converge to the stationary distribution. This would occur despite the stationarity of the shocks in the nonlinear stochastic economy under some further conditions. Conversely, this implies that a wealth distribution exists which is not sensitive to initial conditions (e.g., Chamberlain and Wilson (2000) in Corsetti (2008)).

[127] Because in open economy models with incomplete asset markets the deterministic steady state depends on the initial conditions of the economy, without this function the steady state would be compatible with any level of net foreign assets. This means that in a stochastic environment the variables in the model become non-stationary as net foreign assets follow a unit root process.

$$\max_{C_t, I_{j,t}, B_{H,t}, B_{F,t}, N_t, N_{j,t}, K_{j,t}} E_t \left\{ \sum_{t_0=t}^{\infty} \beta^{t_0-t} \left[U\left(C_{t_0}, (1-N_{t_0})\right) \right] \right\}$$

$$+\beta^{t_0}\lambda^M_{t+t_0}\left(\begin{array}{l} B_{H,t+t_0-1}+Q_t B_{F,t+t_0-1}+P^P_{H,t+t_0}w_{H,t+t_0}N_{H,t+t_0}+P_{NT,t+t_0}w_{NT,t+t_0}N_{NT,t+t_0}+ \\ +P^P_{H,t+t_0}r^K{}_{H,t+t_0}K_{H,t+t_0}+P_{NT,t+t_0}r^K{}_{NT,t+t_0}K_{NT,t+t_0}+\dfrac{\int_0^n \Pi_{H,t+t_0}(h)dh+\int_0^n \Pi_{NT,t+t_0}(nt)dnt}{n}+ \\ +\dfrac{TR_{t+t_0}}{P_{t+t_0}}-\dfrac{B_{H,t+t_0}}{(1+r_{t+t_0})}-\dfrac{Q_{t+t_0}B_{F,t+t_0}}{(1+r^*_{t+t_0})\Phi\left(Q_{t+t_0}B_{F,t+t_0}\right)}-C_{t+t_0}-I_{H,t+t_0}-I_{NT,t+t_0} \end{array}\right)$$

$$+\beta^{t_0}\xi^M_{j,t+t_0}\left((1-\delta)K_{j,t+t_0-1}+I_{j,t+t_0}-\frac{\nu}{2}\left(\frac{I_{j,t+t_0}}{K_{j,t+t_0-1}}-\delta\right)^2 K_{j,t+t_0-1}\right)+$$

$$+\beta^{t_0}\kappa^M_{t+t_0}\left(N_{t+t_0}-N_{H,t+t_0}-N_{NT,t+t_0}\right)$$

$$j=H,NT$$

where instantaneous utility U is a function of a consumption index and leisure $L_t = 1-N_t$, λ^M_t, $\xi^M_{j,t}$ are the marginal values of consumption and investment, respectively; $\kappa^M_{t+t_0}$ is a disutility of labour supply[128].

By setting and solving the sequential Lagrangian problem, one gets the following first order conditions for a representative household:

(3.29) $\quad C_t:\ U_C(C_t, N_t) - \lambda^M_t = 0$

(3.30) $\quad N_t:\ U_N(C_t, N_t) + \kappa^M_t = 0$,

(3.31) $\quad N^j:\ \lambda^M_t P_{j,t} w_{j,t} - \kappa^M_t = 0$

(3.32) $\quad B_{H,t}:\ \dfrac{1}{1+r_t} = E_t \beta \dfrac{\lambda^M_{t+1}}{\lambda^M_t}$

[128] Given the fact that all households are identical their marginal utilities of consumption λ^{Ms}_t and investment $\xi^{Ms}_{j,t}$, and disutility of labour $\kappa^{Ms}_{t+t_0}$ are also identical, and the superscript M could be dropped in the following derivations (notice also that in the steady-state $\lambda^M = \xi^M_j$). See also footnote 126.

$$B_{F,t}: \; U_C(C_t,N_t) = (1+r_t^*)\Phi\left(Q_t B_{F,t}\right)\beta \mathrm{E}_t\left\{U_c(C_{t+1},N_{t+1})\frac{Q_{t+1}}{Q_t}\right\} \tag{3.33}$$

$$I_{j,t}^K: \; \lambda_t^M = \xi_{j,t}^M - \xi_{j,t}^M v\left(\frac{I_{j,t}^K}{K_{j,t-1}} - \delta\right) \tag{3.34}$$

$$\begin{aligned} K_{j,t}: \; \xi_{j,t}^M &= \beta E_t \lambda_{t+1}^M P_{j,t+1} r_{j,t+1}^K \\ &+ \beta E_t \xi_{j,t+1}^M \left((1-\delta) - \frac{v}{2}\left(\frac{I_{j,t+1}^K}{K_{j,t}} - \delta\right)^2 + v\left(\frac{I_{j,t+1}^K}{K_{j,t}} - \delta\right)\left(\frac{I_{j,t+1}^K}{K_{j,t}}\right)\right) \end{aligned} \tag{3.35}$$

where $j = H^P, NT$ and H^P is an index for the home tradable price at the producer level.

Now, combining (3.29) and (3.32) one obtains a standard consumption-savings decision equation for households (i.e., the consumption Euler equation):

$$\frac{1}{(1+r_t)} = \mathrm{E}_t\left[\beta \frac{U_C(C_{t+1},N_{t+1})}{U_C(C_t,N_t)}\right] \tag{3.36}$$

Equations (3.29), (3.30) and (3.31) determine the labour/ leisure choice (i.e., households set wages as a markup over the marginal disutility of labour, which is to say that at the margin, the ratio between marginal utilities of effort and consumption should equal the real wage).

$$P_{j,t} w_{j,t} = \frac{U_N(C_t,N_t)}{U_C(C_t,N_t)} \tag{3.37}$$

Equation (3.32) represents the home consumers' optimal holdings of home bonds. The equivalent of equation (3.32) for the large country and equation (3.33) set conditions for portfolio holdings of foreign bonds:

$$U_C(C_t,N_t) = (1+r_t^*)\Phi\left(B_{F,t} Q_t\right)\beta \mathrm{E}_t\left(U_C(C_{t+1},N_{t+1})\frac{Q_{t+1}}{Q_t}\right) \tag{3.38}$$

And finally, equations (3.34) and (3.35) pin down the optimal path for capital.

$$\text{(3.39)} \qquad \frac{U_C(C_t,N_t)}{1-\nu\left(\frac{I_t^j}{K_{t-1}^j}-\delta\right)} = \beta \mathrm{E}_t\left\{U_C(C_{t+1},N_{t+1})P_{j,t+1}r_{j,t+1} + \left[\frac{U_C(C_{t+1},N_{t+1})}{1-\nu\left(\frac{I_{t+1}^j}{K_t^j}-\delta\right)} * \left((1-\delta)-\frac{\nu}{2}\left(\frac{I_{t+1}^j}{K_t^j}-\delta\right)^2+\nu\left(\frac{I_{t+1}^j}{K_t^j}-\delta\right)\left(\frac{I_{t+1}^j}{K_t^j}\right)\right)\right]\right\}$$

Two things should be noted here. First, when markets are incomplete, the risk-sharing between countries is incomplete. To set up the condition for risk-sharing one needs to combine a foreign consumption Euler equation with the expression for portfolio holdings i.e., eq. (3.38) is combined with the equivalence of equation (3.36) for the foreign country. This yields:

$$\text{(3.40)} \qquad \frac{1}{\Phi\left(B_{F,t}Q_t\right)}\mathrm{E}_t\left[\left(\frac{U_C(C_{t+1},N_{t+1})}{U_C(C_t,N_t)}\right)^{-1}\left(\frac{U_C^*(C_{t+1}^*,N_{t+1}^*)}{U_C^*(C_t^*,N_t^*)}\right)\right] = \mathrm{E}_t\left(\frac{Q_{t+1}}{Q_t}\right)$$

Thus, the difference between a model in which financial markets are complete and one in which they are incomplete is that in the later case the link between the real exchange rate and marginal utilities of home and foreign consumptions holds only in expectations and is affected by the NFA position of households[129]. So as long as there is asset accumulation/ de-cumulation the real exchange rate will be affected. *Ceteris paribus*, there is a negative correlation between the NFA and RER (see also Selaive and Tuesta (2006)). Second, unlike models in which markets are complete, here, since there are costs associated with holdings of foreign currency-denominated bonds, the uncovered interest parity, obtained from combining equation (3.32) and (3.38), does not hold:

$$\text{(3.41)} \qquad \frac{(1+r_t)}{(1+r_t^*)} = \Phi\left(B_{F,t}Q_t\right)\mathrm{E}_t\left(\frac{Q_{t+1}}{Q_t}\right)$$

[129] This in turn implies that the equilibrium dynamic response to productivity shocks can generate endogenous wealth effects.

and the spread in the real interest rates reflects a premium on top of the expected real exchange rate depreciation[130]. This equation implies a negative relationship between the interest rate differential and the NFA position of the economy. A country that accumulates assets faces a smaller implicit cost of bond holding in consequence of which the interest rate differential is smaller.

3.4.2 Firms (supply side)

Intermediate goods producers

In each sector of the economy (T and NT) monopolistic competition is assumed. In the nontradable sector, monopolistic competitors produce a continuum of nontradable intermediate goods using domestic capital and labour (labour is mobile between sectors, but immobile internationally). In the tradable sector, given the importance of the imported intermediate goods in the production process in the NMSs (Laxton and Pesenti (2003), Natalucci and Ravenna (2002, 2007), firms also use the intermediate imported goods, in addition to capital and labour.

Firms supply nontradable output and produce in accordance with the following standard Cobb-Douglas production function:

(3.42) $$Y_{NT,t}(nt) = Y_{NT,t} = A_{NT,t}(K_{NT.t-1})^{\alpha_{NT}}(N_{NT.t})^{1-\alpha_{NT}}$$

where and $A_{NT,t}$ is a sector (and country) specific productivity shock.

The production function for the tradable output $Y_{H,t}(h)$ is of a CES form[131]:

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[130] The risk premium is positive if the home country is a borrower (and negative if the country is a lender). The interest rate differential is larger if the country de-cumulates net foreign assets and smaller if accumulation is observed.

[131] Tradable production function for the large economy is also of the CES form. However, because SOE does not impact the large country, foreign tradable production function comprises of domestic value added and the intermediate domestic good. The demand for the domestic intermediate good exported to the large economy is therefore not modelled explicitly, but described by the *ad hoc* demand function. See Annex C.3 for details.

(3.43) $$Y_{H,t}(h) = Y_{H,t} = \left[\upsilon_H^{\frac{1}{\mu_H}} VA_{H,t}^{\frac{\mu_H - 1}{\mu_H}} + (1-\upsilon_H)^{\frac{1}{\mu_H}} M_t^{\frac{\mu_H - 1}{\mu_H}} \right]^{\frac{\mu_H}{\mu_H - 1}}$$

where $VA_{H,t}$ stands for domestic value added and M_t is an imported intermediate input (i.e., goods which are not considered as capital or consumption goods).

Domestic $VA_{H,t}$ evolves in accordance with the standard Cobb-Douglas production function

(3.44) $$VA_{H,t} = \chi_{H,t}^{\iota - 1} A_{H,t} (K_{H,t-1})^{\alpha_H} (N_{H,t})^{1-\alpha_H}$$

Unlike the production function defined for the NT sector, domestic $VA_{H,t}$ is subject not only to productivity, but also to quality adjustments – i.e., $\chi_{H,t}^{\iota-1}$ is a sector specific quality shock. As in Chapter 2, following Hobijn (2002) and Dury and Oomen (2007), a parameter ι is introduced. It determines the impact of quality changes on marginal costs of the firm. Note that if $\iota - 1 < 0$ quality improvements increase the marginal costs of production (differently to the sectoral productivity improvements)[132].

Finally, for simplicity and given the ongoing debate in the literature on whether prices are indeed sticky, in each sector flexible prices are assumed. Each monopolist chooses its price and commits to satisfying demand at this price. His objective is to maximize profits (minimize costs). Firms take the wage rate, aggregate price indices and the world aggregates as given. As in Selaive and Tuesta (2003, 2006), it is assumed that firms in the nontradable and tradable sectors face flexible prices although they behave as monopolists in selling their products. In setting their prices, they face the following optimal pricing problems:

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[132] Recall that in Chapter 2 quality changes had an economy-wide impact.

$$\max_{P_{NT,t}(nt)} \left[(1-\tau_{NT}) \frac{P_{NT,t}(nt)}{P_t} Y^d_{NT,t}(nt) - \frac{MC^{NT}_t}{P_t} Y^d_{NT,t}(nt) \right]$$

(3.45) $$\text{s.t: } Y^d_{NT,t}(nt) = \left(\frac{P_{NT,t}(nt)}{P_{NT,t}} \right)^{-\sigma_{NT}} Y^d_{NT,t}$$

where $Y^d_{NT,t}(nt)$ is a total individual demand for variety *n* in the nontradable sector, and where $Y^d_{NT,t}$ is aggregate demand for a nontradable good (consumption and investment).

Note further that since households supply homogenous labour and capital (i.e., firms share common factor prices $W_{NT,t}$ and $R_{NT,t}$), and since they face the same productivity and quality shocks, the nominal marginal cost MC_t^{NT} is common across firms. τ_{NT} is a revenue tax in the nontradable sector. Maximization of this function yields the following profit-maximizing price (which is the same at the consumer and producer level)[133]:

(3.46) $$\frac{P_{NT,t}(nt)}{P_t} = \frac{P_{NT,t}}{P_t} = \frac{\sigma_{NT}}{\sigma_{NT}-1} \frac{1}{1-\tau_{NT}} \frac{MC_t^{NT}}{P_t} = mk^{NT} mc_t^{NT}$$

where

$$mk_{NT} = \frac{\sigma_{NT}}{\sigma_{NT}-1} \frac{1}{1-\tau_{NT}} \text{ (NT sector's mark-up),}$$

and where mc_t^{NT} is the real marginal cost in the nontradable sector.

Nominal marginal cost MC_t^{NT} is given by:

(3.47) $$MC_t^{NT} = \frac{\delta TC}{\delta Y_{NT,t}(nt)} = \frac{R_{NT,t}{}^{\alpha_{NT}} W_{NT,t}{}^{1-\alpha_{NT}}}{A_{NT,t}} \left\{ \frac{1}{\alpha_{NT}{}^{\alpha_{NT}} (1-\alpha_{NT})^{1-\alpha_{NT}}} \right\}$$

and can be calculated analogically to MC_t^H in Chapter 2 (see Annex B.3 for details).

---

[133] Given that each non-tradable firm faces the same marginal cost as well as flexible prices, prices of goods are the same across firms. This essentially means that $P_{NT,t}(nt) = P_{NT,t}$.

Real profits in the nontradable sector (in units of home consumption) are:

(3.48) $$\int_0^n \frac{\Pi_{NT,t}(nt)dnt}{n} = \Pi_{NT,t} = P_{NT,t}Y_{NT,t} - P_{NT,t}r_{NT,t}K_{NT,t} - P_{NT,t}w_{NT,t}N_{NT,t}$$

In the tradable sector, each domestic tradable firm, given the demand for its good h determines the price that maximises its profits[134]. Therefore, each tradable firm solves the following optimal pricing problem:

$$\max_{P^P_{H,t}(h),P^{*P}_{H,t}(h)} \left\{ \left((1\text{-}\tau_H)\frac{P^P_{H,t}(h)}{P_t} - \frac{MC_{H,t}}{P_t} \right) Y^d_{H,t}(h) + \left(Q_t(1\text{-}\tau_H)\frac{P^{*P}_{H,t}(h)}{P^*_t} - \frac{MC_{H,t}}{P_t} \right) Y^{*d}_{H,t}(h) \right\}$$

$s.t.$

(3.49) $$Y^d_{H,t}(h) = \left(\frac{P^P_{H,t}(h) + \zeta P_{NT,t}}{P_{H,t}} \right)^{-\sigma_H} Y^d_{H,t}$$

$$Y^{*d}_{H,t}(h) = \left(\frac{P^{*P}_{H,t}(h) + \zeta P^*_{NT,t}}{P^*_{H,t}} \right)^{-\sigma_H} Y^{*d}_{H,t}$$

where $Y^d_H(h)\,(Y^{*d}_H(h))$ is a total individual domestic (foreign) demand for variety f in the tradable home sector, and where $Y^d_{H,t}$ $(Y^{d*}_{H,t})$ is an aggregate domestic (foreign) demand for a tradable home good (consumption and investment).

From the problem above, the following optimal prices for producers are obtained (note that they are not the same as for consumers) [135] [136]:

(3.50) $$\frac{P^P_{H,t}(h)}{P_t} = \frac{P^P_{H,t}}{P_t} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\left(\frac{MC^H_t}{P_t} + \frac{\zeta(1-\tau_H)}{\sigma_H}\frac{P_{NT,t}}{P_t} \right)$$

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[134] Notice that since a small country case is considered here, demand for foreign goods is a negligible part of the total exports of the Foreign (large) country.

[135] Since each tradable firm faces the same marginal cost and faces flexible prices, goods prices charged at the domestic market are the same across firms (similar to the NT sector), but different between domestic and foreign markets.

[136] See Annex C.5 for derivations.

$$\frac{P^{*P}_{H,t}(h)}{P^{*}_{t}} = \frac{P^{*P}_{H,t}}{P^{*}_{t}} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\left(\frac{MC_t^{\ H}}{P_t}\frac{1}{Q_t} + \frac{\zeta(1-\tau_H)}{\sigma_H}\frac{P^{*}_{\ NT,t}}{P^{*}_{\ t}}\right) \tag{3.51}$$

Note that (3.50) and (3.51) can be re-written as[137]:

$$\frac{P^{P}_{H,t}}{P_t} = \underbrace{\frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\left(1 + \frac{\zeta(1-\tau_H)}{\sigma_H} mk_{NT}\frac{MC_t^{\ NT}}{MC_t^{\ H}}\right)}_{mk_H}\frac{MC_t^{\ H}}{P_t} \tag{3.52}$$

$$Q_t \frac{P^{*P}_{H,t}}{P^{*}_{\ t}} = \underbrace{\frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\left(1 + \frac{\zeta(1-\tau_H)}{\sigma_H} mk_{NT}\frac{MC_t^{\ NT*}}{MC_t^{\ H}}\right)}_{mk_F}\frac{MC_t^{\ H}}{P_t} \tag{3.53}$$

It is clear that sectoral mark-ups both within a country (i.e. $mk_H \neq mk_{NT}$) and between the domestic and foreign economy (i.e. $mk_F^{*} \neq mk_H$) do not equalize[138]. Because domestic and foreign tradable mark-ups do not equalize, the LOOP at the producer level does not hold either. The exchange rate pass-through is incomplete[139].

Using (3.13), the tradable price for consumers in the domestic economy can be expressed as:

$$\frac{P_{H,t}(h)}{P_t} = \frac{P_{H,t}}{P_t} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\left(\frac{MC_t^{\ H}}{P_t} + \frac{\zeta(1-\tau_H)}{\sigma_H}\frac{P_{NT,t}}{P_t}\right) + \zeta\frac{P_{NT,t}}{P_t} \tag{3.54}$$

and for the exported good:

$$\frac{P^{*}_{H,t}(h)}{P^{*}_{\ t}} = \frac{P^{*}_{H,t}}{P^{*}_{\ t}} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\left(\frac{MC_t^{\ H}}{Q_t P_t} + \frac{\zeta(1-\tau_H)}{\sigma_H}\frac{P^{*}_{\ NT,t}}{P^{*}_{\ t}}\right) + \zeta\frac{P^{*}_{\ NT,t}}{P^{*}_{\ t}} \tag{3.55}$$

---

[137] See Annex C.5 for derivations.

[138] Sectoral markups within and between countries equalize when the distribution cost parameter is set to zero, i.e. $\zeta = 0$, and when price elasticities of demand faced by each producer and tax rates equalize.

[139] See Corsertti and Dedola (2005) for a discussion on the role of elasticity of demand for domestic goods in explaining the break in LOOP, and the role of distributive trade in lowering this elasticity (as well as derivations in Annex C.4).

Foreign consumer prices can be expressed analogously. Thus, the presence of distribution services is also one of the channels violating PPP.

As in the nontradable sector case, in order to calculate marginal cost of production of tradables, MC_t^H, the same approach is used as that described in Annex B.3, Chapter 2, for the whole economy. However, given the CES production function in the H sector, the calculated nominal MC_t^H is of the CES form:

$$(3.56)\quad MC_t^H = \frac{\delta TC}{\delta Y_{H,t}(h)} = \left\{ \begin{array}{l} \upsilon_H \left[\dfrac{1}{\chi_{H,t}^{t-1} A_{H,t}} \dfrac{1}{\alpha_H^{\alpha_H} (1-\alpha_H)^{1-\alpha_H}} \left(R_{H,t}^{\alpha_H} W_{H,t}^{1-\alpha_H} \right) \right]^{1-\mu_H} + \\ +(1-\upsilon_H)(P_{M,t})^{1-\mu_H} \end{array} \right\}^{\frac{1}{1-\mu_H}}$$

where $P_{M,t}$ is a domestic currency price of the imported intermediate good for which the law of one price holds[140]. Unlike in the nontradable sector case, MC_t^H cost can change in response not only to changes in quality but also productivity.

The tradable goods producer chooses the inputs of production (capital, labour and imported good) to minimise the cost of production of the required output:

$$(3.57)\quad \begin{array}{l} \min_{Y_{H,t}} R_{H,t}K_{H,t} + W_{H,t}N_{H,t} + P_{M,t}M_t \\ s.t.\ Y_{H,t} = \left[\upsilon_H^{\frac{1}{\mu_H}} VA_{H,t}^{\frac{\mu_H-1}{\mu_H}} + (1-\upsilon_H)^{\frac{1}{\mu_H}} M_t^{\frac{\mu_H-1}{\mu_H}} \right]^{\frac{\mu_H}{\mu_H-1}} \end{array}$$

From the cost minimisation problem above the following ratio is obtained:

[140] Notice that $P_{M,t}$ is the price of the imported intermediate good used in domestic production. This domestic production is available for sale as a consumption or investments good either at home or abroad at the price $P_{H,t}$ and $P_{H,t}^*$, respectively. Analogously, $P_{F,t}^*$ and $P_{F,t}$ are the foreign and domestic price of the foreign consumption good and $P_{M,t}^*$ is the price of the imported intermediate good used in the foreign production (see Annex C.3).

(3.58) $$\frac{R_{H,t}K_{H,t-1}}{\alpha_H}=\frac{W_{H,t}N_{H,t}}{1-\alpha_H}$$

as well as a functional form determining demand for the imported intermediate good M_t:

(3.59) $$\frac{P_{M,t}}{P^P_{H,t}}=\frac{MC_t^H}{P^P_{H,t}}(1-\upsilon_H)^{\frac{1}{\mu_H}}\left(\frac{Y_{H,t}(h)}{M_t}\right)^{\frac{1}{\mu_H}}$$

Real profits in the tradable sector (in units of domestic consumption) read as:

(3.60) $$\int_0^n\frac{\Pi_{H,t}(h)dh}{n}=\Pi_{H,t}=P^P_{H,t}Y_{H,t}-P^P_{H,t}r_{H,t}K_{H,t}-P^P_{H,t}w_{H,t}N_{H,t}$$

3.4.3 Fiscal policy

The Government in the domestic economy collects revenue taxes from firms. These taxes are then redistributed to households in the form of lump-sum transfers TR (the government subsidy is used to eliminate the steady-state mark-up distortions). This is done in a way that in each period there is a balanced budget.

(3.61) $$\int_0^n(\tau_{NT}P_{NT,t}(nt)Y_{NT,t}(nt)+\tau_H P^P_{H,t}(h)Y_{H,t}(h))di=\int_0^n\frac{TR_t}{P_t}(h)dh$$

3.4.4 Stochastic Environment and Equilibrium

The equilibrium of the small open economy is characterized upon aggregation of:

1) allocations and wages for home consumers:

   $C_t, I^K_{H,t}, I^K_{NT,t}, B_{H,t}, B_{F,t}, W_{H,t}, W_{NT,t}$

2) allocations and prices for home firms:

$K_{H,t-1}, K_{NT,t-1} N_{H,t}, N_{NT,t}, P^P_{H,t}, P_{NT,t}, P_{M,t}$

3) allocations and prices for foreign firms:

   $K^*_{F,t-1}, K^*_{NT,t-1}, N^*_{F,t}, N^*_{NT,t}, P^{*P}_{H,t}, P^P_{H,t}, P^*_{M,t}, P^*_{NT,t}$

4) rental rates for capital: $R_{H,t}, R_{NT,t}$

5) fiscal policies;

such that households and firms' allocations solve the households' and firms' problems (i.e., the first order conditions), and that the following market clearing conditions are satisfied[141]:

(3.62) $$B_{H,t} = 0$$

(3.63) $$N^d_t = N_{H,t} + N_{NT,t} = N^s_t$$

(3.64) $$I_t = I^K_{H,t} + I^K_{NT,t}$$

(3.65) $$Y_{H,t} = C_{H,t} + C^*_{H,t} + I_{H,t} + I^*_{H,t}$$

(3.66) $$Y_{NT,t} = C_{NT,t} + I_{NT,t} + \zeta(C_{H,t} + C_{F,t} + I_{H,t} + I_{F,t})$$

(3.67) $$Y_t = \frac{P^P_{H,t} Y_{H,t}}{P_t} + \frac{P_{NT,t} Y_{NT,t}}{P_t}$$

Market clearing conditions are as follows. Condition (3.62) requires that since only domestic consumers have access to domestic bonds, the net supply of these bonds must be zero in equilibrium. Condition (3.63) states that, in equilibrium, labour market requires equalization of total labour demand and supply. Condition (3.64) is the constraint imposed on an economy-wide investment processes (as stressed above, there are no constraints on investment, ensuring capital mobility across sectors), and is necessary given the two separate capital stocks. Goods' market equilibrium condition (3.65) states that total demand in the H sector comprises demand for goods demanded by domestic and foreign consumers $\left(C_{H,t}, C^*_{H,t}\right)$ as well as domestic and

---

[141] Note that market clearing for domestic variety h must satisfy: $Y_{H,t}(h) = nC_{H,t}(h) + (1-n)C^*_{H,t}(h) + nI_{H,t}(h) + (1-n)I^*_{H,t}(h)$, i.e., the aggregate consistency condition requires that individual and per capita variables coincide for all t.

exported investment goods $\left(I_{H,t}, I^*_{H,t}\right)$. Goods' market equilibrium condition (3.66) states that total demand in the NT sector is made up of consumption and investment demand in the NT sector, and the demand from distributors who need to distribute tradable domestic and foreign consumption goods, as well as tradable domestic and foreign investment goods used in the H sector. Finally, the last market clearing condition (3.67) indicates that total real domestic output must be equal to the sum of H and NT production[142].

The model closes with the specification of balance of payments (in real terms), which can be obtained from (3.28) and after substituting for goods' market equilibrium constraints:

(3.68)
$$\underbrace{\frac{Q_t B_{F,t}}{(1+r_t^*)\Phi\left(Q_t B_{F,t}\right)} - Q_{,t} B_{F,t-1}}_{\Delta NFA} = \frac{P^P_{H,t}}{P_t}\left(C^*_{H,t} + I^*_{H,t}\right) + \frac{P_{M,t}}{P_t} M^*_t - \frac{P^P_{F,t}}{P_t}\left(C_{F,t} + I_{F,t}\right) - \frac{P_{M,t}}{P_t} M_t$$

where M^*_t stands for the large country import of the intermediate input from the small open economy[143].

Equation (3.68) equates the change in net foreign assets (NFA) with the trade balance (i.e. the difference between export and import). For example, if domestic imports are greater than exports (i.e. domestic investment is bigger than savings), then the discrepancy must be balanced by the inflow of foreign capital (i.e. current account deficit and de-accumulation of the NFA).

The current account, CA, is equal to the change in NFA:

(3.69)
$$CA_t = B_{F,t} - B_{F,t-1}$$

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[142] To see why output is valued at producer prices, see the tradable producer maximization/pricing problem as well as footnote 124.
[143] See Annex C.3 for details.

The exogenous driving forces in the economy include technology, quality and preference shocks, which follow stochastic processes:

(3.70) $$\log A_{H,t+1} = \rho_{A_H} \log A_{H,t} + \varepsilon_{t+1}^{A_H}$$

(3.71) $$\log A_{NT,t+1} = \rho_{A_{NT}} \log A_{NT,t} + \varepsilon_{t+1}^{A_{NT}}$$

(3.72) $$(\iota - 1)\log \chi_{H,t+1} = \rho^{\chi_H} (\iota - 1)\log \chi_{H,t} + \varepsilon_{t+1}^{\chi_H}$$

(3.73) $$\log \Upsilon_{C,t+1} = \rho_{\Upsilon_C} \log \Upsilon_{C,t} + \varepsilon_{t+1}^{\Upsilon_C}$$

(3.74) $$\log \Upsilon_{N,t+1} = \rho_{\Upsilon_N} \log \Upsilon_{N,t} + \varepsilon_{t+1}^{\Upsilon_N}$$

(3.75) $$\log A_{F,t+1}^{*} = \rho_{A_F^{*}} \log A_{F,t}^{*} + \varepsilon_{t+1}^{A_F^{*}}$$

(3.76) $$\log A_{NT,t+1}^{*} = \rho_{A_{NT}^{*}} \log A_{NT,t}^{*} + \varepsilon_{t+1}^{A_{NT}^{*}}$$

Preference shocks are introduced to allow investigation of the effects of changes on the demand side of the economy in a non-monetary framework.

Decompositions of some international variables:

Given the price indices in the model, and the presence of nontradable goods, home bias and distribution services, real exchange rate can be decomposed in the following manner:

(3.77) $$Q_t = \frac{P_t^{*}}{P_t} = \underbrace{\frac{P_{T,t}^{*}}{P_{T,t}}}_{Q_{EXT,t}} \underbrace{\frac{\left[\gamma^{*} + (1-\gamma^{*})\left(\frac{P^{*}{}_{NT,t}}{P^{*}{}_{T,t}}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}}{\left[\gamma + (1-\gamma)\left(\frac{P_{NT,t}}{P_{T,t}}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}}}_{Q_{INT,t}} = Q_{EXT,t} Q_{INT,t}$$

where $Q_{EXT,t}$ is the external real exchange rate and $Q_{INT,t}$ is the internal real exchange rate.

External real exchange rate, $Q_{EXT,t}$, can be further decomposed (recall from Chapter 2 that in the SOE set-up $P^*_{F,t} = P^*_t$ (or $P^*_{F,t} = P^*_{T,t}$ in the two-sector model)) into:

$$(3.78) \qquad Q_{EXT,t} = \underbrace{\frac{P^*_{F,t}}{P_{F,t}}}_{LOOP} \underbrace{\frac{P_{F,t}}{P_{H,t}}}_{TOT} \underbrace{\left[(1-\omega) + \omega \left(\frac{P_{F,t}}{P_{H,t}} \right)^{1-\phi} \right]^{\frac{1}{\phi-1}}}_{ELASTICITY}$$

These three elements which impact the movements of the external real exchange rate are called as follows. The first is called 'LOOP' as it is related to the price discrimination across countries. If LOOP holds (i.e., if distribution services are absent in the model), the first component is equal to 1[144]. The second element is called 'TOT' as it represents terms of trade movements. It equals 1 when distribution services are excluded from the model and when home bias is symmetric. The third element of this decomposition is called 'Elasticity', and is inversely proportional to the terms of trade, i.e., when TOT appreciates (depreciates), it always depreciates (appreciates) for the values of ϕ different from one. For $\phi = 1$ and $\omega = 0.5$ (symmetric home bias), this component of the external real exchange rate equals 1.

To see more explicitly how distribution services affect the movements of the real exchange rate, it is useful to re-write Q_t in the following way:

$$(3.79) \qquad Q_t = \frac{\left[\lambda^* \left(P^{*P}_{H,t} + \zeta P^*_{NT,t} \right)^{1-\phi} + \left(1-\lambda^* \right) \left(P^{*P}_{F,t} + \zeta P^*_{NT,t} \right)^{1-\phi} \right]^{\frac{1}{1-\phi}}}{\left[\lambda \left(P^{P}_{H,t} + \zeta P_{NT,t} \right)^{1-\phi} + \left(1-\lambda \right) \left(P^{P}_{F,t} + \zeta P_{NT,t} \right)^{1-\phi} \right]^{\frac{1}{1-\phi}}} \frac{\left[\gamma^* + (1-\gamma^*) \left(\frac{P^*_{NT,t}}{P^*_{T,t}} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}}{\left[\gamma + (1-\gamma) \left(\frac{P_{NT,t}}{P_{T,t}} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}}$$

which in the log-linear form reads as:

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144 Notice that for simplicity the model assumes identical elasticities of demand for the same good across countries (this is not the case in Benigno and Thoenissen (2003), who however do not include distribution services in their model). This means that without distribution services the LOOP holds in the model, as firms are unable to price discriminate across the different markets.

$$\hat{Q}_t = \hat{P}^*_t - \hat{P}_t = \underbrace{\zeta \frac{1}{1+\zeta}\left(\hat{P}^*_{NT,t} - \hat{P}_{NT,t}\right)}_{1} - \underbrace{\left(1-\zeta\frac{1}{1+\zeta}\right)\left[\lambda \hat{P}^P_{H,t} + (1-\lambda)\hat{P}^P_{F,t}\right]}_{2} + \underbrace{+\left(1-\zeta\frac{1}{1+\zeta}\right)\left[\lambda^* \hat{P}^{*P}_{H,t} + (1-\lambda^*)\hat{P}^{*P}_{F,t}\right]}_{3} + \tag{3.80}$$

$$\underbrace{+\frac{(1-\gamma^*)}{\gamma^*\left(\frac{1}{1+\zeta}\right)^{1-\varepsilon} + (1-\gamma^*)}\left(\hat{P}^*_{NT,t} - \hat{P}^*_{T,t}\right) - \frac{(1-\gamma)}{\gamma\left(\frac{1}{1+\zeta}\right)^{1-\varepsilon} + (1-\gamma)}\left(\hat{P}_{NT,t} - \hat{P}_{T,t}\right)}_{4}$$

and where the terms 1, 2 and 3 represent market segmentation channels (Q_t^{MS}) caused by the international price discrimination due to the presence of distribution services and the presence of home bias. The term (4) is the internal real exchange channel (Q_t^{int})[145].

The respective channels (features of the model) affect the real exchange rate in the following way. Home bias, which arises as domestic consumers prefer home over foreign goods (i.e. $\lambda > 1-\lambda$[146]) together with the presence of the nontraded good in the model, violate purchasing power parity (i.e. the real exchange rate is no longer equal one). At the same time, the presence of the nontraded good in the model, as mirrored by the Q_t^{int} channel, represents the international version of the HBS effect where movements in the real exchange rate are caused by movements of relative prices of nontraded and traded goods between countries. Distribution services result in a difference between the price at which the same good is sold to consumers and producers, i.e., $P^P_{H,t} \neq P^{*P}_{H,t}$ ($P^P_{F,t} \neq P^{*P}_{F,t}$) and $P_{H,t} \neq P^*_{H,t}$ ($P_{F,t} \neq P^*_{F,t}$), and thus inviolate LOOP (see Annex C.5 for details). This also contributes to the violation of PPP in the model and - because of its impact on the elasticity of substitution between H and F tradable goods – should increase the volatility of the real exchange rate.

145 The technical details of the method used to perform the log-linearization above can be found in Annex C.6. The same Annex also presents detailed steps taken to log-linearize the simpler decomposition of the RER, in the model without distribution services.

146 For home bias to occur in the large economy, the reverse is true.

It should be stressed that in the presence of distribution services the real exchange rate is not only affected through movements of the relative price of traded goods, as well as nontraded to traded goods (as would be the case in a model with nontradable goods and home bias in preferences only), but also through movements of the relative price of nontraded goods between the two economies (see term 1 in (3.80)). Thus, the movements of this price add one more element, which can contribute to the volatility of the real exchange rate.

Equation (3.80) can be further simplified by assuming a symmetric home bias, (i.e. it is assumed that both, home and foreign country value the consumption of locally produced goods to the same degree, $\lambda = 1 - \lambda^{*}$), and equal shares of tradable goods in the consumption basket between small and large economy, $\gamma = \gamma^{*}$ (this assumption is also made in model simulations):

(3.81)

$$\widehat{Q_t} = \underbrace{\underbrace{\zeta \frac{1}{1+\zeta}\left(\hat{P}^*_{NT,t} - \hat{P}_{NT,t}\right)}_{1} + \left(1-\zeta\frac{1}{1+\zeta}\right)\left[(1-\lambda)\hat{P}^{*P}_{H,t} + \lambda \hat{P}^{*P}_{F,t} - \lambda \hat{P}^{P}_{H,t} - (1-\lambda)\hat{P}^{P}_{F,t}\right]}_{2} +$$

$$+ \underbrace{\frac{(1-\gamma)}{\gamma\left(\frac{1}{1+\zeta}\right)^{1-\varepsilon} + (1-\gamma)}\left[\left(\hat{P}^*_{NT,t} - \hat{P}^*_{T,t}\right) - \left(\hat{P}_{NT,t} - \hat{P}_{T,t}\right)\right]}_{3} =$$

$$= \underbrace{\underbrace{\zeta\left(\frac{1}{1+\zeta}\right)\left(\hat{P}^*_{NT,t} - \hat{P}_{NT,t}\right)}_{1} + \left(1-\zeta\frac{1}{1+\zeta}\right)\left[\hat{P}^{*P}_{H,t} - \lambda \hat{P}^{*P}_{H,t} + \lambda \hat{P}^{*P}_{F,t} - \lambda \hat{P}^{P}_{H,t} - \hat{P}^{P}_{F,t} + \lambda \hat{P}^{P}_{F,t}\right]}_{2} +$$

$$+ \underbrace{\frac{(1-\gamma)}{\gamma\left(\frac{1}{1+\zeta}\right)^{1-\varepsilon} + (1-\gamma)}\left[\left(\hat{P}^*_{NT,t} - \hat{P}^*_{T,t}\right) - \left(\hat{P}_{NT,t} - \hat{P}_{T,t}\right)\right]}_{3}$$

From the last equality of equation (3.81), it can be seen that without distribution services, the RER decomposition in (3.81) is equivalent to equation (C52) presented in Annex C.6, which means that $\hat{Q}_t = \hat{Q}_t^{nds}$, where $\hat{Q}_t^{nds}$ stands for the real exchange rate without distribution services (if $\zeta = 0$, prices at the consumer and producer level equalize, LOOP holds (as equal elasticities of demand for the same good across countries were assumed)); and PPP deviations are only caused by the standard HBS effect (channel 3).

Now, the relationship between terms of trade at the consumer and producer level can be also established. Since at the consumer level, TOT is defined as $T_t \equiv \frac{P_{F,t}}{P_{H,t}}$, and at the producer level as $T_t^P \equiv \frac{P^P_{F,t}}{P^P_{H,t}}$, the relationship between these variables in the log-linear form reads as:

(3.82) $$\hat{T}_t^P \equiv (1+\zeta)\hat{T}_t$$

Without distribution services (i.e. $\zeta = 0$), the LOOP at the border holds. As a result, terms-of-trade at the producer and consumer level equalize.

3.5 UTILITY FUNCTION, PARAMETRIZATION AND SIMULATION

3.5.1 Baseline Calibration

It is assumed that household preferences are additively separable and that the utility function takes the same form as proposed for the basic model of Chapter 2 (see equation (2.1)). The strategy for the calibration of structural parameters is the same as described in Chapter 2. The calibrated parameter values are compiled in Table C.1 in Annex C.9. As the values of the parameters which are common to both models are discussed in depth in Chapter 2, here, only the values of the parameters which are unique to the expanded model are evaluated.

Consequently, following Stockman and Tesar (1995), the elasticity of substitution between traded and nontraded consumption and investment goods, ε, is set to 0.44 [147]. The price elasticity of demand faced by each producer in the nontradable sector, σ_{NT}, equals 6. This value, together with the revenue taxes of 0.1 in both sectors[148], and the size of the distribution margin $\mu^D = \zeta \frac{P_{NT}}{P_T}$ set at 37.5 percent (i.e., the distribution parameter ζ is set at 0.6), implies the elasticity of substitution between differentiated goods in the Home tradable sector, σ_H, of 9.6 (see Annex C.8 for derivations). Notice that the chosen size of the distribution margin is not only lower than the 49.7 percent adopted by Corsetti et al. (2008), Selaive and Tuesta (2006) or Thoenissen (2006) for the two-country symmetric DSGE models, but also lower than the 50 percent value picked for the Polish economy by Kolasa (2008, 2009). The choice of the more conservative value is motivated by two factors. First, as documented by Goldberg and Campa (2006), the Polish exchange rate exhibits a higher degree of pass-through when compared with the US exchange rate. Second, as discussed in Section 2, the share of distribution services in the Polish

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[147] Some papers adapt higher values for this elasticity following the findings of Mendoza (1991). However, Mendoza, unlike Stockman and Tesar, does not include developing countries in his sample.
[148] Calculated by the author, based on OECD data for Poland, as GDP at 1995 constant prices less GVA at 1995 constant prices and averaged over 1995Q1-2008Q1.

value added is around 26 percent (Goldberg and Campa (2006) show that in 2000 this number was 32 percent). Moreover, the calibration above ensures that the steady-state markups μ in both sectors equalize and come to 1.33, which is a plausible value in the literature (see Chapter 2).

As in Chapter 2, the elasticity of substitution between home and foreign traded goods ϕ is assumed to be 2 in the baseline calibration. However, in the model with distribution services, for the chosen size of distribution margins, this means the implied value of this elasticity Ω as low as 1.25 (i.e. $\Omega = 1.25$, see Annex C.4 for derivations).

The shares of traded goods in the consumption and investment indices γ are equal to 0.4. The choice of this value is governed by the calculation of the shares of T and NT goods in the Gross Value Added (GVA) in Poland between 1995Q1 and 2008Q1. They are 0.3 and 0.7, respectively[149]. As in Chapter 2, the home bias parameter λ is set to be 0.7, which implies a degree of openness ω of 0.3. This, together with the share of domestic value added υ_H in the production of home tradable good of 0.5, matches the 0.3 share of imports in Polish GDP[150]. The elasticity of substitution between domestic value added and imported good M, μ_H, equals 0.5, as in Natalucci and Ravenna (2002, 2007). Following Selaive and Tuesta (2006), for simplicity, the capital shares in the nontradable and tradable sectors for the intermediate goods producers equalize and are set to 0.4 (see also Thoenissen (2006) for the model with distribution services). The parameter governing the costs of undertaking positions in the international asset markets ($NFA\_P = -\Phi'(\bar{b})\bar{Y}$), is set to 0.007 following Rabanal and Tuesta (2006)[151]. This implies that a decrease in

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[149] A higher value of this share is also tried as the share of tradable goods in HICP indices in Poland is larger and equals 0.7 (see Section 2 for the discussion on the issue). Since this choice almost equalises the steady-state shares of the non-tradable and tradable sectors in the total output – something not observed in the data - the GVA values are relied on.

[150] The share of exports and imports in Polish GDP was also considered as a measure of openness. However, as this would imply a lack of consumption home bias in preferences, the import-to-GDP ratio was used instead.

[151] The parameters' NFA_P measures the elasticity of the interest rate differential to changes in the NFA position. The bigger the elasticity the bigger the effect of the current account channel on the interest rate differential (e.g. current account deficits in less developed countries should require higher

the net foreign assets to the steady-state output ratio by 100 basis points is associated with a 70 basis point higher domestic interest rate than foreign interest rate. This value is higher than the 0.001 proposed by Benigno (2001) and used by Benigno and Theonissen (2003), but lower than 0.01 used by Theonissen (2006)). As this value measures the elasticity of the interest rate differential to changes in the net foreign asset position in the, it seems reasonable to choose a higher value for a relatively less developed economy (as these countries need to compensate investors for higher risks and thus pay higher risk premium) (see also footnote 130).

Table 3.2.2 presents the decomposition of the steady-state GDP that results from the baseline calibration described in Chapter 2 and above:

Table 3.2.2 Structure of the Polish and model economies

Structure	Polish economy	Steady-state
I/GDP	21	18
C/GDP	82	82
M/GDP	33	31
GDP_T/GDP[a]	30	29
GDP_NT/GDP[a]	70	71

Note: I – investment, GDP - Gross Domestic Product, C – consumption, I – import, GDP_T – GDP in the tradable sector, GDP_NT – GDP in the nontradable sector (a. sectoral empirical GDP was calculated using the sectoral Gross Value Added (GVA) data. Therefore, the presented shares of sectoral output are expressed in terms of the GVA). Columns, 'Polish economy' and 'Steady-state', are expressed in percent of GDP. The values were calculated over the period 1995-2008.

Source: Author's calculation based on the OECD data and the steady-state solution of the model

From Table 3.2, it is clear that the proposed parameter values result in the model steady-state values of the decomposed GDP that resembles the structure of the Polish economy.

spreads between domestic and foreign interests rates to reflect higher risk premium faced by those economies).

Calibration of shocks

In what follows, the calibration of exogenous driving forces in the economy is reviewed. As a reminder, the dynamics of the model economy are driven by seven exogenous processes: 5 domestic (tradable and nontradable productivity shocks, a quality shock originated in the tradable sector and shifts in households' preferences regarding consumption and labour), and 2 foreign (tradable and nontradable productivity shocks)[152].

As pointed out in Chapter 2, the absence of a long data span as well as the lack of reliable data on capital and employment make it difficult to estimate reliable productivity processes for Poland, and thus the variances (and covariances between Poland and the eurozone) of productivity innovations. This is even more so for the sectoral data. Despite clear difficulties, as in Chapter 2, an attempt is made to estimate sectoral variances and the persistence of the productivity innovations as lognormal AR(1) processes[153] (as discussed in Chapter 2, given the weak evidence on correlation of shocks among the euro zone countries (see Jondeau and Sahuc (2006) in Kolasa (2008, 2009)), the exogenous processes for productivity were not specified as a VAR model)[154]. With no priors for correlations between sectoral shocks, none was assumed (although Lipińska (2008, 2008a) assumes strongly correlated sectoral productivity shocks, Kolasa (2008, 2009) assumes zero)).

However, the AR(1) coefficients turned out to be too low to be able to replicate the volatility of sectoral outputs in Poland (similar to the results obtained in Chapter 2). Therefore, and given the ambiguous findings of other studies on productivity processes (Backus et al. (1992) or Baxter and Crucini (1995)), an alternative strategy

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[152] The foreign preference shock was also tried. Since it did not alter the results much, it was not included in the final model simulations.

[153] Sectoral productivity series are calculated as country-wide series in Chapter 2 (with the exception that the share of capital in both sectors is assumed to be 0.4). The data on employment and gross value added for the years 2000Q1-2008Q4 was sourced from Eurostat. The obtained series were then de-trended using a Hodrick-Prescott (HP) filter.

[154] Also, as stressed by Baxter and Farr (2005), even for developed countries, it is impossible to estimate with great precision the parameters of the exogenous process for de-meaned, de-trended productivity specified as a bivariate VAR(1). Therefore, for example, studies by Backus et al. (1992) or Baxter and Crucini (1995), suggest qualitative features of the standard Solow residual measure of productivity shocks, such as it's high persistence and a positive cross-country correlation (although it is less clear whether the cross-country spillover effects are positive or not).

for calibrating the exogenous processes for the de-meaned, de-trended sectoral productivity is followed.

In terms of persistence, sectoral productivity shocks for Poland are assumed to be highly persistent (although a sensitivity analysis was performed with respect to the $AR_H(1)$ coefficient). A first order serial correlation process of 0.95 is assumed in both sectors – a value commonly used in the literature in respect of technology shocks (see, for example, King and Rebelo (1999)). As in Chapter 2, the correlation of structural productivity shocks between Poland and the euro area is assumed to be zero. Similarly, the sectoral shocks are assumed to be orthogonal in the baseline calibration. However, as a part of sensitivity analysis, the case where tradable and nontradable productivity shocks are moderately correlated (0.2) is also analysed. In terms of variances of sectoral productivity shocks, values are calibrated which best match the volatility of the sectoral outputs in the Polish data in years 1995Q1-2008Q1. As the selected magnitudes coincide with the variances of productivity innovations obtained from the estimated AR(1) models and since they lie comfortably within the margins estimated by Kolasa (2008, 2009), some confidence can be put in them[155]. In terms of quality processes, only quality improvements originating in the tradable sector are described, as there is no way of measuring them in the nontradable sector. In the absence of available priors for quality adjustments, the quality process χ_H is modelled as a lognormal AR(1) process (as proposed in Chapter 2, available data on export unit values is used). Finally, the size of the consumption preference shock is the same as chosen by Natalucci and Ravenna (2007) in the two-sector DSGE model for the Czech Republic. The persistence of the preference shocks is also taken from Natalucci and Ravenna (2007), and is slightly higher than that assumed in the one-sector model of Chapter 2 (0.85 versus 0.7). The labour preference shock and its persistence is the same as in Chapter 2. Productivity processes for the euro area are in line with the priors chosen by Kolasa (2008) and in line with business cycle literature for developed countries (see, for example, Kollman (2002) for UK, Japan in Germany). Admittedly, calibrated shocks are only rough guesses, but they do provide some indication of innovation processes in the

[155] The calibration of shocks in this paper is similar to that of Baxter and Faar (2005).

Polish economy. Table 3.2.3 below sets out the structure of the shocks used in the model calibrated for the Polish economy:

Table 3.2.3 Volatilities of shocks

Shocks to:	Prod. H	Prod. NT	Quality H	Cons. Prefer.	Labour Prefer.	Prod. F*	Prod. NT*
$E(\varepsilon^2)$	7.29E-04	2.25E-04	1.69E-04	8.10E-05	2.50E-03	6.40E-05	6.40E-05
AR(1)	0.95	0.95	0.95	0.85	0.95	0.95	0.95

Note: Author's calculations. The tradable and nontradable productivity, quality, consumption and labour preference shocks are labelled: ε_H , ε_{NT} , ε_{q_H} , ε_{Υ_C} and ε_{Υ_L} , respectively. ε_F^* , ε_{NT}^* , stand for tradable and nontradable productivity shocks occurring in the large economy.

Source: Author's calculations.

3.5.2 Simulation Results

Matching the Moments

The aim of this section is to see how well the model performs in terms of matching the moments of the key business cycle statistics for Poland as well as its selected international variables.

Table 3.2.4 and Table 3.2.5 present the empirical as well as theoretical standard deviations, autocorrelations and correlations of the selected variables. The data for the calculation of the statistics for Poland covers the period 1995Q1 through 2008Q1 (current account and employment data was only available from 2000Q1)[156]. To retrieve the cycle data, all variables (in logs) were Hodrick-Prescott filtered with the smoothing parameter of 1600.

In terms of matching the moments, the model performs reasonably well on some, but not all the investigated variables. For the baseline parameterisation (i.e., column II in

[156] Due to the lack of data on average hours worked, Eurostat values for number of people employed were used as a proxy for a measure of labour in the model. Sectoral employment was calculated in the same manner as sectoral GVA. See Annex C.1 for details.

Table 3.2.4), the model is able to roughly match the observed volatility of economy wide and tradable output, consumption and investment, as well as economy wide and nontradable employment. The volatility of nontradable output is slightly higher than in the data, but is comparatively similar. Also, the model does appear to match the volatility of the real exchange rate (and its persistence) relatively well. Although, this volatility is still around 20% lower than the actual observed for Poland, this may be regarded as a relatively good outcome given that there are no monetary disturbances in the model[157], and the fact that the baseline simulations were run for the more conventional for the IRBC models value of the trade elasticity (i.e., for the values which makes the domestic and foreign tradable goods more substitutable to each other). It is also noteworthy that, as in the data, the real exchange rate is more volatile than the terms-of-trade (recall that in the model with tradable goods only, real exchange rate was less volatile than the terms of trade). However, the model underpredicts the observed trade balance, current account and – despite the presence of distributive services - terms-of-trade volatility. It also overpredicts tradable employment and internal real exchange rate volatility (notice that although the model generates more volatile internal RER, this gap may in fact be smaller. This is because the volatility of the internal RER may depend on the choice of indices and may very as indicated by the results presented in 3.2.1).

[157] i.e., many IRBC models find it difficult to replicate the documented in the data volatile and persistent real exchange rates (see Chari, et al. (2002), Heathcote and Perri (2002) or the volatility of RER reported for the baseline calibration in Chapter 2).

Table 3.2.4 Model and Data Second Moments

Variable	Standard Deviations							
	Model							Data
	NFA_P=0.007						NFA_P=0.001	
	ϕ=2					ϕ=0.6	ϕ=0.6	
Column Number	I	II	III	IV	V	VI	VII	
$AR_H(1)$	0.95	0.95	0.95	0.95	0.75	0.95	0.95	
ζ	0	0.6	0.9	0.6	0.6	0.6	0.6	
Shocks	all	all	all	prod. only	all	all	all	
GDP	1.61	1.54	1.55	1.38	1.53	1.29	1.30	1.34
GVA_T	2.61	2.04	1.95	1.82	1.94	1.21	1.22	2.15
GVA_NT	1.83	1.69	1.69	1.51	1.69	1.66	1.67	1.28
Consumption	1.11	1.11	1.12	0.44	1.08	1.10	1.11	1.06
Investment	6.55	6.31	6.55	5.53	6.52	6.39	6.44	6.52
Employment	1.53	1.52	1.52	0.30	1.55	1.51	1.51	1.48
Employment_T	2.03	3.56	4.10	2.42	3.34	3.40	3.39	1.80
Employment_NT	1.57	1.64	1.63	0.73	1.75	1.60	1.61	1.60
Trade balance[a]	0.25	0.14	0.12	0.11	0.15	0.14	0.14	1.46
Current account[a]	0.25	0.14	0.12	0.11	0.15	0.14	0.15	1.13
Terms-of-Trade	1.81	2.23	2.48	1.92	2.12	3.50	3.40	4.47
RER	**2.11**	**4.44**	**5.45**	**3.52**	**4.49**	**6.06**	**5.92**	**5.30**
Internal RER	2.29	1.70	1.49	1.37	1.70	1.81	1.79	1.11

Note: NFA_P refers to the parameter governing the costs of undertaking positions in the international asset market, ϕ is the elasticity of substitution between home and foreign tradable goods. In the line 'Column Number' a number is assigned for every performed model simulation. $AR_H(1)$ stands for the persistence of the tradable productivity shock. ζ is the share of distribution services. In the line called 'Shocks', the kinds of shocks affecting the SOE are stated (i.e., 'all' stands for the model scenario in which all shocks are switched on; 'prod. only' stands for the case in which only domestic and foreign productivity shocks, and a domestic quality shock are at work).

Source: Author's calculation based on the OECD data and the model simulations.

In terms of the AR(1) coefficients (see Table 3.2.5), the model underpredicts the persistence of the employment variable, which is close to the unit root in the data. The persistence of the NT and T employment as well as RER and internal RER are slightly lower in the model. Nonetheless, given the so-called 'persistence anomaly', which is usually a feature of the DSGE models, the persistence of the RER appears to be relatively well predicted by the model (notice that this was also the case in Chapter 2). As in Chapter 2, in contrast to the data, the model exhibits significant terms-of-trade persistence. Persistence of consumption is also too high (although less so).

Looking at the correlations of selected variables with output (see Table 3.2.5), the model matches the procyclicality of all business cycle variables observed in the Polish data. The best match is observed for tradable output, consumption, investment, tradable employment and terms-of-trade. However, the procyclicality of nontradable output appears to be too high in the model, while economy wide and nontradable employment exhibits a correlation with output that is too low. In terms of international variables, the terms-of-trade, as in the data, are procyclical. They are also positively correlated with the RER.

Table 3.2.5 Model and Data Autocorrelations and Correlations

					Output	Out_T	Out_NT	Cons.	Invest.	Emp.	Emp_T	Emp_NT	TB	CA	TOT	RER	RER_INT
AUTOCORRELATION																	
Variable					**Output**	**Out_T**	**Out_NT**	**Cons.**	**Invest.**	**Emp.**	**Emp_T**	**Emp_NT**	**TB**	**CA**	**TOT**	**RER**	**RER_INT**
data					0.64	0.74	0.65	0.41	0.77	0.95	0.86	0.87	0.46	0.42	0.05	0.80	0.85
model, NFA_P=0.007	**elasticity** 2	**AR_H 0.95**	**zeta**	0.6	**0.72**	**0.72**	**0.71**	**0.68**	**0.70**	**0.71**	**0.71**	**0.71**	**0.70**	**0.70**	**0.73**	**0.72**	**0.71**
	2	AR_H 0.95		0	0.72	0.71	0.71	0.68	0.70	0.71	0.71	0.71	0.70	0.70	0.72	0.73	0.71
	0.6	AR_H 0.95		0.6	0.70	0.71	0.70	0.67	0.69	0.71	0.59	0.70	0.70	0.70	0.72	0.72	0.65
	2	AR_H 0.75		0.6	0.67	0.64	0.68	0.67	0.66	0.60	0.65	0.63	0.66	0.66	0.65	0.72	0.70
CORRELATION WITH OUTPUT																	
Variable					**Output**	**Out_T**	**Out_NT**	**Cons.**	**Invest.**	**Emp.**	**Emp_T**	**Emp_NT**	**TB**	**CA**	**TOT**	**RER**	**RER_INT**
data					1.00	0.70	0.68	0.61	0.78	0.83	0.61	0.78	-0.24	-0.56	0.29	-0.02	-0.12
model, AR_H=0.95	**elasticity** 2	**high NFA_P**	**zeta**	0	1.00	0.75	0.88	0.57	0.81	0.32	0.38	0.26	-0.18	-0.18	0.59	0.61	0.23
	2	high NFA_P		0.6	**1.00**	**0.80**	**0.98**	**0.60**	**0.82**	**0.29**	**0.54**	**0.08**	**-0.41**	**-0.42**	**0.59**	**0.70**	**0.53**
	2	high NFA_P		0.9	1.00	0.84	0.99	0.58	0.83	0.29	0.59	0.06	-0.54	-0.55	0.62	0.73	0.60
	0.6	high NFA_P		0.6	1.00	0.84	0.99	0.57	0.77	0.28	0.55	0.07	-0.79	-0.79	0.57	0.73	0.69
	0.6	low NFA_P		0.6	1.00	0.84	0.99	0.57	0.77	0.28	0.54	0.09	-0.79	-0.79	0.56	0.72	0.67
CORRELATION WITH RER																	
Variable					**Output**	**Out_T**	**Out_NT**	**Cons.**	**Invest.**	**Emp.**	**Emp_T**	**Emp_NT**	**TB**	**CA**	**TOT**	**RER**	**RER_INT**
data					0.02	0.24	-0.17	-0.01	0.02	0.24	0.39	0.29	-0.14	0.34	0.16	1.00	0.31
model, AR=0.95	**elasticity** 2	**high NFA_P**	**zeta**	0	0.61	0.21	0.73	0.17	0.70	0.17	0.55	-0.02	-0.11	-0.12	0.15	1.00	0.84
	2	high NFA_P		0.6	**0.70**	**0.44**	**0.75**	**0.19**	**0.75**	**0.13**	**0.73**	**-0.18**	**-0.18**	**-0.19**	**0.45**	**1.00**	**0.93**
	2	high NFA_P		0.9	0.73	0.55	0.76	0.20	0.75	0.14	0.76	-0.17	-0.29	-0.31	0.57	1.00	0.94
	0.6	high NFA_P		0.6	0.73	0.62	0.82	0.22	0.76	0.18	0.52	-0.02	-0.69	-0.70	0.80	1.00	0.93
	0.6	low NFA_P		0.6	0.72	0.61	0.81	0.20	0.76	0.18	0.52	-0.02	-0.66	-0.67	0.79	1.00	0.93

Note: AR(1) refers to the first order autocorrelation coefficient. NFA_P refers to the parameter governing the costs of undertaking positions in the international asset market, ϕ is the elasticity of substitution between home and foreign tradable goods. $AR_H(1)$ stands for the persistence of the tradable productivity shock.

Source: Author's calculation based on the OECD data and the model simulations.

Also, the negative correlation of the trade and CA balances are reasonably matched by the model (recall that in Chapter 2 the model's trade balance was positively correlated with output). The most significant discrepancy between the data and model appears in the correlation between output and the RER and internal RER, which is very low and negative in the data, but high and positive in the model. Looking at correlations of the selected variables with the RER, the model overpredicts the co-movements of this variable with investment and internal RER. Likewise, unlike in the data, the co-movement of the RER with nontradable output, nontradable employment and current account is negative. However, the model does correctly mimic the correlation of tradable output, economy wide employment, tradable employment, trade balance and terms-of-trade with the RER. Although, the model still finds a positive correlation between consumption and the RER, this correlation is significantly lower than in the complete market model of Chapter 2.

In what follows below, a sensitivity analysis is conducted and the results are described. In the first step, in an attempt to improve the performance of the model in terms of the terms-of-trade and real exchange rate volatility, the distributive parameter, ζ, was increased to 0.9 (for $\phi = 2$, see column IV in Table 3.2.4). With the higher share of distribution services, the business cycle statistics did not change much (the volatility of tradable output, trade balance and current account dropped marginally and the volatility of tradable employment increased marginally). However, the match of international variables improved. Now, the real exchange rate volatility is only slightly higher than in the data (column IV in Table 3.2.4). Also, the volatilities of terms-of-trade and internal RER better reflect the data. With the higher share of distribution services in the model, the persistence of selected variables remains the same (Table 3.2.5). Also, the correlations of selected variables with the output and the RER remain unaltered (the largest change is observed for correlations of trade balance and current account variables with output, i.e. they acyclicality becomes more pronounced).

In the second step, the distribution channel was shut down (i.e., $\zeta = 0$ with $\phi = 2$, column I in Table 3.2.4). This resulted in a significant drop in RER volatility as well as the terms-of-trade. The internal RER became much too volatile. The volatility of output (including nontradable and tradable) also increased. However, the volatility of employment (tradable in particular), as well as trade balance and current account fits the data better. Given that the AR(1) coefficients as well as the direction of correlations of output and RER with other variables did not change much without the distribution channel, they are not reported.

Given the importance of elasticity of substitution between home and foreign-produced goods for the volatility and persistence of exchange rates, in the third step, the value of this elasticity was lowered to 0.6 (i.e., column VI in Table 3.2.4). This means that the value of the implied elasticity, Ω, became 0.38. Although, it is a fairly low number, it is not implausible (for example, Corsetti et al. (2008) use the implied value of 0.5 for the baseline calibration, Taylor (1993) estimates for the trade elasticity, for the U.S., is 0.39), and allows a better sensitivity check. Lower ϕ brings the volatility of output, tradable employment, terms-of-trade and RER closer to the data. This however happens in expense of the tradable output and internal RER fit.

In the fourth step, the persistence of the productivity shock was lowered to 0.75. This hardly impacted both business cycle and international variables[158]. If anything, tradable output, employment and terms-of-trade became slightly less volatile. On the other hand, real exchange rate, trade balance and current account became more volatile. With less memory in the tradable productivity shock, AR(1) coefficients are somewhat lowered, but not drastically. Again, given that correlations with output and RER did not change significantly, they are not reported in Table 3.2.5.

Given that the true value of the parameter measuring bond holding costs, NFA_P is uncertain, in a separate simulation the value was lowered to 0.001 (for the $\phi = 0.6$). Second moments in result of this simulation are reported in column VII of Table 3.2.4. Business cycle statistics as well as the statistics for trade balance, current account and internal exchange rate remained unaltered when compared with those presented in column VI. However, with higher risk sharing, the volatility of terms-of-trade and the RER became lower. Intuitively, when households are less constrained to borrow abroad following an increase in domestic productivity

[158] Only when the persistence of the productivity shock was lowered to 0.45 – the number obtained from the estimation of the AR(1) processes – were the business cycle statistics significantly different from those observed in the data.

(i.e., they face lower NFA_P), a smaller rise in the terms of trade is required to clear the market. Looking at the correlation of model variables with output and the RER, with the smaller cost of bond holdings, they are hardly changed. Given that AR(1) coefficients also hardly changed, they are not reported.

Finally, in the last step of the sensitivity analysis, to see how much of the observed RER volatility is due to the presence of demand shocks in the model, these shocks were shut off. The results are presented in column IV of Table 3.2.4. Clearly, the RER is still fairly volatile, indicating that productivity shocks are an important source of its movement. However, with productivity shocks only, the model cannot account for the volatility of consumption observed in the data.

In summary, the performed sensitivity analysis show that the model second moments are mostly sensitive to changes in the elasticity of substitution between home and foreign tradable goods. Lower elasticity mainly improves the fit of terms-of-trade and RER volatility. These improvements occur irrespective of whether the elasticity is lowered directly or indirectly via the higher share of distribution services in the model (however, increasing the share of distribution services, also improves the fit of the internal real exchange rate). Nonetheless, the fit of some business cycle statistics worsens. In terms of model autocorrelations and correlations, they do not react much to changes in model parameters. Given that there exists a trade-off between the fit of terms-of-trade and RER and other variables, and taking into account that the fit of the model is already fairly good for the baseline calibration, this calibration is preferred[159].

Impulse responses

Before the impulse response functions are presented below, it is useful to set out how the model can be expected to reflect the impact of each supply-side shock on the real

[159] As mentioned above, the model does not include monetary disturbances, which empirically – to some degree - matter for the movements of the Polish real exchange rate, Therefore, and given the relatively high values of the terms-of-trade and RER variance for the baseline calibration even without nominal shocks, this calibration seems even more plausible.

exchange rate, and the expected impact of changes in the elasticity of substitution between H and F tradable goods, ϕ[160].

Positive productivity shock originating in the tradable sector

RER appreciation is ambiguous. In the model with a nontradable good, a positive productivity shock in the tradable sector puts pressure on real exchange rate appreciation via the internal real exchange rate channel (see term 3 in equation (3.81)), as predicted by the HBS proposition[161], and via a positive wealth effect associated with the transfer problem discussed in the introduction to Chapter 3. However, in response to a positive productivity shock, the terms-of-trade must depreciate to clear the market for the domestic tradable output, which may lead to an overall real exchange rate deterioration.

Which channel of RER movements prevails is not entirely clear, and depends – among other things – on the elasticity of the substitution of home and foreign tradable goods ϕ. The larger the elasticity, the less prices of tradable domestic consumption have to drop for the market to clear (H and F goods are closer substitutes; a smaller terms-of-trade deterioration is required to switch demand from foreign to home produced tradable goods). Thus a higher ϕ makes the HBS and transfer effects more likely to prevail, and result in the overall real exchange rate appreciation. But adding distributive trade costs to the model *lowers* the elasticity of demand (see Annex C.4). Therefore, two opposite effects can be observed. On one hand, the presence of distribution services, because it lowers Ω, also lowers the impact of a shock on the real exchange rate appreciation arising from an appreciation of the internal real exchange rate. On the other hand, provided wealth effects are strong enough, in a model with home bias and a distributive sector, there is a

[160] The focus here is on supply-side shocks, as the recent productivity and quality improvements in the NMSs are believed to be the most important contributors to the persistent RER appreciation observed in these countries. Emphasis is also placed on the elasticity of substitution between H and F tradable goods ϕ, given its significance in determining the behaviour of the real exchange rate.

[161] Although a positive tradable productivity shock decreases the prices of tradable goods, it leads to increases in the price of non-tradable goods. This is because the resulting increase in the tradable sector wage is passed on to the nontradable sector due to the homogeneity of wages across sectors. This drives nontradable prices upwards, which in turn causes a reduction in the relative price of tradable to nontradable goods (see Błaszkiewicz et al. (2005) for more detail).

possibility that terms-of-trade may in fact appreciate, contributing to overall RER appreciation (see Corsetti et al. (2008)). This is because in a model with home bias, provided the elasticity of the substitution of home and foreign tradable goods ϕ is sufficiently *low*, a negative income effect (arising from lower prices of tradable goods) should more than offset the substitution effect (arising from the increased domestic demand for domestic tradables). Then, for the world market to clear, terms-of-trade (and the real exchange rate) must appreciate, boosting domestic wealth and demand. Moreover, distributive trade costs may actually diminish the tradable price decreases associated with the positive productivity shock, as both the HBS and transfer effects drive the cost of distribution services up, putting an upward pressure on the relative price of domestic and foreign tradable goods at the consumer level (see term 1 in equation (3.81)).

And finally, because of lower risk-sharing in the model with incomplete markets, in response to a positive tradable shock, the terms-of-trade do not have to depreciate by as much as in the complete market case, as there is less risk sharing (Home does not need to transfer as much purchasing power to Foreign, and the required improvement in trade balance is smaller). The fact that terms-of-trade depreciate less in the incomplete market framework should contribute to overall real exchange rate appreciation.

Positive quality shock originating in the tradable sector

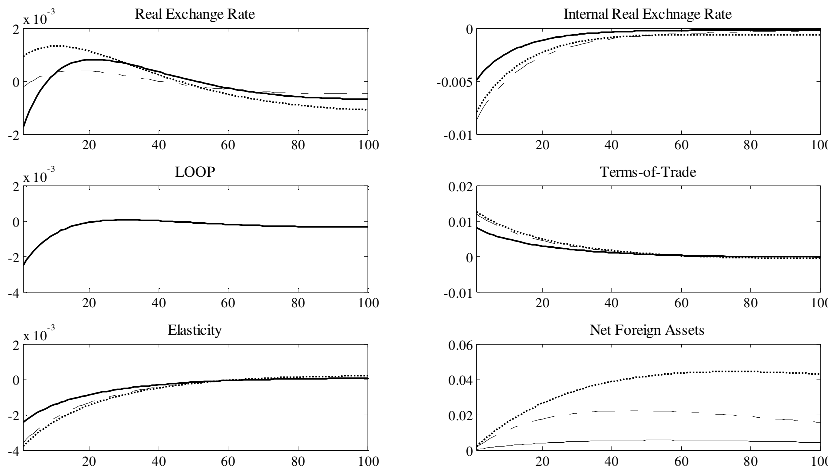
RER appreciation is ambiguous. Although in the case when the quality parameter, ι, is less then one, the marginal cost is an increasing function of quality, a resulting increase in the tradable price should lead to real exchange rate appreciation (via the terms-of-trade channel), but may also result in the depreciation of the internal real exchange rate. This is because quality improvements in the tradable sector may in fact result in price decreases in the nontradable sector (because of their lower relative quality). This would mean that although term 2 in equation (3.81) should lead to a RER appreciation, terms 1 and 3 are likely to bring about a depreciation of the real exchange rate. Which element prevails depends on the importance of nontradable prices in real exchange rate movements.

Positive productivity shock originating in the nontradable sector

RER depreciation is expected. This is because when the economy is impacted by a positive productivity shock in the nontradable sector, an increase in the relative price of traded to nontraded goods in the home country with respect to the foreign country results in real exchange rate depreciation. Moreover, given the presence of distribution services in the model, the positive productivity shock to the NT sector should also lower the price of the domestic tradable good, as the nontradable component constitutes a fraction of that good. Therefore, all the terms of (3.81) are expected to depreciate.

In what follows below, the model driving processes are graphed as impulse response functions. Each of the three figures (Figure 3.2, Figure 3.3, Figure 3.4) comprises 6 graphs. The first graph presents the RER movements itself. The second represents the movements of the internal real exchange rate. The next three graphs are the elements of the external RER decomposition presented in equation (3.78). The sixth graph presents the dynamics of net foreign assets, which are crucial to understanding movements of the RERs associated with wealth effects.

Figure 3.2. Orthogonalized Positive Productivity Shock - Tradable Sector



Note: Solid line: the share of distribution services is 0.6 and NFA_P=0.007. Dash-dotted line: the share of distribution services is zero and NFA_P=0.007. Dotted line: the share of distribution services is zero and NFA_P=0.001.

Source: Author's calculations.

Figure 3.2 presents impulse responses to a positive productivity shock in the tradable sector. For the baseline calibration (solid line) the model generates an appreciation of the RER in response to a positive productivity shock despite the terms-of-trade deterioration (proportionally diminished by the 'Elasticity' channel as explained in section 3.4.4). This is because, terms-of-trade deterioration is outweighed by the increases in the relative price of nontraded to traded goods (the internal real exchange rate), which means that the substitution effect is greater than the income wealth effect. The RER appreciation is strengthened by the presence of distribution services in the model, i.e., the 'LOOP' channel.

When distribution services are excluded from the model, the LOOP holds and the observed RER appreciation is lower (dash-dotted line)[162]. This is despite the fact that, without distribution services, the contribution of the internal RER channel and

[162] Notice that without distribution services, given the flexible price assumption, the real variables in the model resemble the stochastic properties of the shocks, which means that impulse response functions capture not only short but also long run components of real exchange rate movement.

'Elasticity' channel toward RER appreciation is greater. However, since there is no contribution from the LOOP channel and since the price of distribution services also impacts terms-of-trade, which depreciates more in the model where distributive trade costs are absent (i.e. the nontradable price increases are not passed onto tradable prices), the overall real exchange rate strengthens less. Nonetheless, similar to the specification with distribution services, negative wealth effects related to the lower price of domestic tradable goods are not strong enough to lead to the ultimate terms-of-trade improvement that arises in the model. In fact, in the model without distribution services, positive wealth effects arising from the fact that consumers substitute away from imported goods are higher (i.e., larger NFA accumulation is observed). Although this result differs from Corsetti et al. (2008) and Selaive and Tuesta (2003, 2006), it is similar to that of Theonissen (2006), who also includes distributive trade costs in his model[163].

And finally, when the home economy faces a smaller implicit cost of bond holdings (the dotted line), NFA_P (i.e. when it is set at 0.001 as opposed to at 0.007 under the baseline calibration), the real exchange rate depreciates[164]. This is because the smaller cost of undertaking positions in the international financial market increases risk-sharing. So, even if in this case the accumulation of NFA is larger, which all things being equal should result in a larger RER appreciation, with the smaller cost of bond holdings, risk sharing is greater, as a result of which terms-of-trade depreciates more (i.e. more purchasing power needs to be transferred to foreigners), and outweighs the appreciation of the internal real exchange rate. This suggests that the presence of distribution costs is not essential for RER appreciation, although it does contribute to it.

A positive nontradable productivity shock results in the expected depreciation of the RER (via both, the internal, LOOP and terms-of-trade channels), which is larger in the model without distribution services (see Figure 3.3). This is because, when

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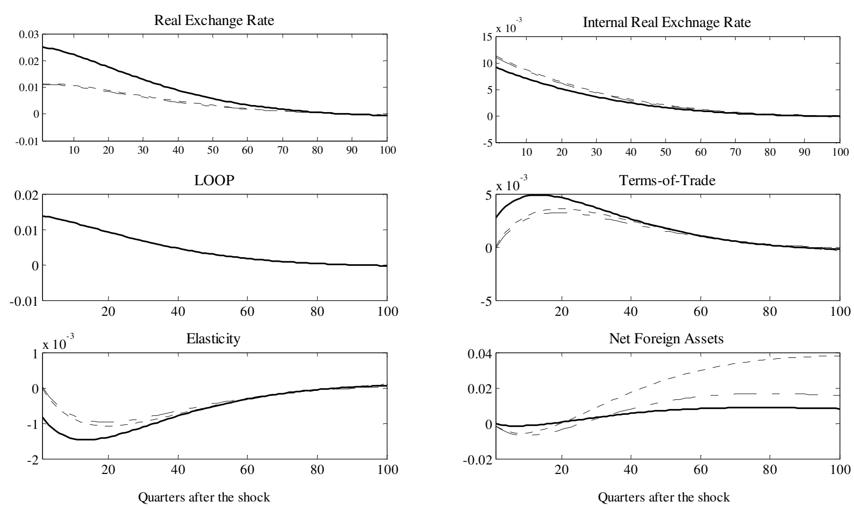
[163] All these papers look at the two-country symmetric case with distribution services, but only in the Corsetti et al. (2008) and Selaive and Tuesta's (2006) papers do terms-of-trade improve together with RER appreciation in response to a positive productivity shock. In contrast, but as in the model presented here, in Theonissen (2006), both the terms-of-trade and real exchange rate depreciate.
[164] This happens irrespectively of whether LOOP holds or not in the model.

distribution services are present in the model, despite the smaller depreciation of the internal real exchange rate, the terms-of-trade deteriorate significantly more (and thus 'Elasticity' channel appreciates less). The latter happens because the positive productivity shock to the NT sector, which lowers the nontradable price also diminishes the associated increases in the price of a domestic tradable good. When the risk-sharing is greater (i.e., when NFA_P=0.001), the RER deterioration is marginally larger, as terms-of-trade deteriorate slightly more.

Figure 3.3. Orthogonalized Positive Productivity Shock - Nontradable Sector

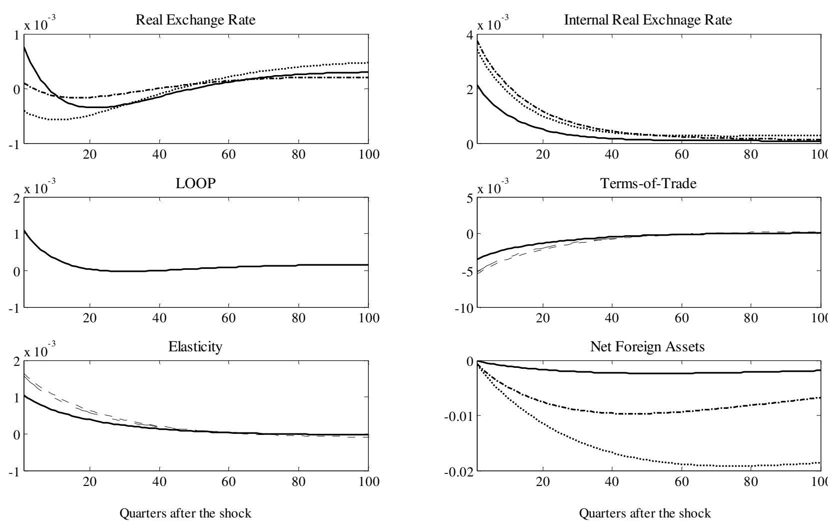


Note: Solid line: the share of distribution services is 0.6 and NFA_P=0.007. Dash-dotted line: the share of distribution services is zero and NFA_P=0.007. Dotted line: the share of distribution services is zero and NFA_P=0.001.

Source: Author's calculations.

And finally, a positive quality shock (see Figure 3.4), indeed brings about a terms-of-trade improvement, but in contrast to the results of Chapter 2, the total impact of this shock on the change in the RER rate is positive (i.e., the RER depreciates). This is due to three factors: the depreciation via the 'Elasticity' channel, depreciation related to the break in the LOOP, and price decreases in the nontradable sector. Simulations performed for the model where ζ is set to zero still lead to RER depreciation, although this depreciation is smaller. This is because even if the depreciation of the internal real exchange rate is larger for the model without distributive trade costs (i.e. negative wealth effects associated with a transfer problem are observed), the terms-of-trade improvement is greater (as a drop in the nontradable price does not contribute to changes in the price of domestic tradables anymore), and there is no depreciating contribution from the 'LOOP channel'. The appreciation of the RER associated with the positive quality shock is however possible when the model moves further away from financial autarky (i.e. NFA_P=0.001). This is because, in this case, the internal RER depreciates less and terms-of-trade strengthens more. This appreciation, unlike in the case of the positive productivity shock, is associated with the CA deterioration (i.e. the depletion of the NFA is observed) and thus negative wealth effects are observed.

Figure 3.4. Orthogonalized Positive Quality Shock - Tradable Sector



Note: Solid line: the share of distribution services is 0.6 and NFA_P=0.007. Dash-dotted line: the share of distribution services is zero and NFA_P=0.007. Dotted line: the share of distribution services is zero and NFA_P=0.001.

Source: Author's calculations.

Notice that the gap between terms-of-trade responses to tradable and nontradable productivity as well as quality shocks in the models with and without distribution services is largest in the case of a positive nontradable shock. This is because this shock triggers larger changes in the nontradable price, which is also a fraction of the price of tradable goods (see equation (3.54)).

Given that a positive productivity shock to the tradable sector results in an appreciation of the real exchange rate (not a standard result in DSGE models), sensitivity analysis was performed with respect to the trade elasticity and correlation of sectoral shocks. The results show that the RER appreciation is fairly robust to changes in the value of ϕ [165]. Only when home and foreign goods become closer complements (i.e., ϕ =1.6), does the real exchange rate depreciate. This compares to ϕ=1.9 when distribution services are excluded from the model. When tradable and nontradable productivity innovations are assumed to be correlated, with correlation coefficient equal to 0.2, at the baseline value of ϕ=2 real exchange rate depreciation is observed. For the real exchange rate to appreciate, the elasticity of the substitution between home and foreign tradable goods ϕ needs to be set at 3 or higher. However, RER volatility at ϕ=3 is still reasonably high and equals 3.86.

Variance Decomposition

This section establishes the contribution of each shock in the model to explaining the variation of the real exchange rate, the internal real exchange rate as well as terms-of-trade. Additionally, the impact of each shock on the LOOP channel is examined. Table 3.2.6 presents the decomposition of the variance for these four international variables for three model scenarios: low and high share of distribution services as well as the scenario when $\zeta = 0$.

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[165] For convenience, the related impulse responses are not shown. They are however available upon request.

Table 3.2.6 Variance decomposition

	ε_H	εq_H	ε_{NT}	ε^*_F	ε^*_{NT}	$\varepsilon_{\Upsilon c}$	$\varepsilon_{\Upsilon L}$
			ζ=0.6				
Q	0.3	0.06	55.07	1.93	26	3.75	12.89
Q^{int}	13.69	2.57	49.93	3.97	21.37	2.08	6.38
LOOP	1.77	0.33	55.22	2.43	25.49	3.38	11.37
TOT	55.66	10.45	10.42	1.34	6.78	2.94	12.42
			ζ=0.9				
Q	0.34	0.06	56.68	1.51	24.74	3.36	13.31
Q^{int}	11.21	2.11	52.49	3.28	21.43	2.06	7.41
LOOP	1.3	0.24	56.82	1.85	24.49	3.13	12.18
TOT	45.19	8.49	18.14	1.07	9.33	3.12	14.67
			ζ=0				
Q	0.05	0.01	48.44	4.42	31.7	3.44	11.94
Q^{int}	24.04	4.51	40.01	6.79	20.15	1.18	3.31
TOT	74.08	13.91	1.4	1.78	1.62	1.24	5.96

Note: The tradable and nontradable productivity, quality, consumption and labour preference shocks in the SOE are labelled: ε_H, ε_{NT}, ε_{q_H}, ε_{Υ_C} and ε_{Υ_L}, respectively. ε^*_F, ε^*_{NT}, stand for tradable and nontradable productivity shocks occurring in the large economy. Real exchange rate, internal RER, the movements of the RER due to the break away from LOOP, and terms of trade are abbreviated as Q, Q^{int}, LOOP, T , respectively. ζ stands for values of distribution services in the price of tradable goods.

Source: Author's calculations.

The results obtained from this exercise indicate that under the low distributive trade scenario of $\zeta = 0.6$, around 55% of the real exchange rate volatility is due to the positive shock originating in the nontradable sector; 26% of the variance arises from the positive nontradable shock originating in the foreign country; and 13% comes from the labour preference shock. Other shocks, including productivity and quality improvements in the tradable sector, are of little importance in explaining real exchange rate movements. The channel, which captures the deviations from the LOOP, is similarly impacted by these shocks. Likewise, the internal RER is also mainly driven by the nontraded productivity shock. Nonetheless, the contribution of the tradable shock to the internal real exchange rate's movements is larger than to the movements of RER, and is around 14 percent. Terms-of-trade, are however dominated by productivity shocks in the tradable sector. Because terms-of-trade are dominated by productivity shocks in the tradable sector, these productivity shocks cannot be observed in the movement of the real exchange rate (more precisely, because terms-of-trade deteriorate in response to the tradable productivity shock, it absorbs productivity differentials in the tradable sector). This result is similar to that of Altissimo et al. (2005), who looks at sources of inflation differential in the eurozone countries.

An increase in the share of distributive trade hardly alters the way particular shocks affect the RER. As for the other two elements, the internal RER and TOT, the importance of the productivity shock decreases with the higher share of distributive trade. Surprisingly, excluding distribution services from the model does not alter the result that a nontradable productivity shock dominates the movements of the RER (the shock is still responsible for 48% of the RER variance). This suggests that adding distributive trade costs to the model does not change the conclusion that the real exchange rate is driven by shocks which originate in the nontraded sector.

The fact that the model suggests that tradable productivity improvements are only important in explaining movements in terms-of-trade and do not contribute to movements of the real exchange rate is rather surprising, and runs counter to the commonly accepted view that improvements in tradable sector productivity lead to inflation differentials between New and Old Member States. One way of interpreting this result is that asymmetric shocks originating in the nontradable sector are more important than tradable shocks in explaining inflation differentials between Poland and the eurozone.

Therefore, in the context of Polish euro adoption and taking into account the fact that nontradable sectors are typically sheltered from international competition, it is important to introduce measures which would increase competitiveness in these sectors – for example, via lower labour costs, higher factor mobility (labour and capital), creation of incentives for adoption of new technologies, deregulation of market for services, and release of capacity constraints in the labour market. The existence of flexible adjustment mechanisms should contribute to lower volatility of the real exchange rate, in turn creating less scope for independent monetary policy. Moreover, if price increases in the nontradable sector are caused by large capital inflows and are not combined with productivity increases in this sector, this will lead to higher inflation in Poland than in the eurozone. This outcome may not be equilibrium phenomena, but rather a sign of overheating pressures – a scenario that seems to be playing out in Estonia, for example.

3.6 CONCLUSIONS

In this chapter, a more complex version of the basic SOE-DSGE model of real exchange rate determinants presented in Chapter 2 was put forward. Although, the model proposed here can still be classified as a canonical real business cycle model, it is augmented by additional channels of real exchange rate movements. In addition to the home bias channel and quality factors investigated in the basic model of Chapter 2, the model includes incomplete markets, a nontradable sector, and distributive trade costs. Next, the model is simulated with the shocks and parameters calibrated to the Polish economy.

Unlike standard two-sector DSGE models (see for example Benigno and Theonissen (2003)), the model in this chapter generates RER appreciation in response to tradable productivity improvements (i.e. consistent with the HBS-like and wealth effects). This appreciation is possible despite the depreciation of the country's terms-of-trade. Appreciation of the RER is also possible when the quality shock associated with the lower bond holding costs is included in the model. In this case, however, the country's terms-of-trade improves.

It should be noted that real RER appreciation in response to a positive productivity shock was previously shown in papers by Corsetti et al. (2008) and Selaive and Tuesta (2006), who utilize two-country two-sector symmetric DSGE models. There are no papers which show this in a SOE framework – the contribution of this chapter. Nontheless, unlike here, in both papers by Corsetti et al. (2008) and by Selaive and Tuesta (2006), RER appreciation is combined with terms-of-trade improvement. Nonetheless, Theonissen (2006), who works with a two-country two-sector symmetric DSGE model with distribution trade costs, argues that the appreciation attained by Corsetti et al. (2008) is only possible thanks to the utilization of an endogenous discount factor in the model (i.e. closing the model with the cost of bond holdings rules out the possibility of the negative transmission mechanism according to Theonissen (2006))[166].

Also, unlike in Vilagi (2005), who argues that the HBS-like effect can only be achieved in NOEM models when pricing-to-market is incorporated into the model, in this chapter it is shown that although the presence of distribution costs (a form of pricing-to-market) does contribute to the RER appreciation, it is not essential for this appreciation to happen. What is crucial, however, is the existence of wealth effects arising in the incomplete market framework (notice that Vilagi's model assumed complete markets) – i.e. for the model calibration, the required appreciation is only possible for higher values of bond holdings costs (i.e., when the model moves further away from the complete market set-up). When this cost was lowered to the values used by Benigno and Theonissen (2003), the real exchange rate did depreciate in response to a positive tradable productivity shock (similar to the complete market models of Vilagi (2005) and that proposed in Chapter 2).

Another parameter on which the model RER appreciation depends on is the elasticity of substitution between home and foreign tradable goods. Although Vilagi (2005) concludes that no intermediate degree of international substitution exists that would ensure the appreciation of the RER, here, it is shown that such appreciation is not only possible, but is also possible for values which are in line with those typically used by the IRBC literature (i.e., for values which make goods closer substitutes). Indeed, the presence of distribution costs is important here. When distribution costs are excluded from the model, the lowest possible value of the elasticity of substitution for which the RER appreciates is 1.9. This compares with 1.6 in the model with trade costs.

Another notable result obtained from the model simulations is RER volatility and persistence, which is shown to match the Polish data fairly well. This is encouraging as existing SOE-DSGE models used for policy purposes for the NMSs either do not report statistics for the RER, or fail to match its empirical variance (see, for example,

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[166] It should be noted however that Selaive and Tuesta (2006) do obtain a negative transmission despite closing the model with bond holding costs.

Ravenna and Natalucci (2007) or Lipińska (2008, 2008a)). Given that the model put forward in this chapter was able to explain approximately 80 percent of the RER volatility in Poland, the importance of other real shocks could be investigated (for example, a fiscal policy shocks could be looked at). However, since in Chapter 1 it was shown that to some degree nominal shocks still move the Polish and Czech real exchange rates, the observed empirical RER volatility could perhaps be better matched by adding nominal rigidities and monetary policy to the model of RER determinants for these countries.

In order to ascertain the real exchange rate determinants in Poland, variance decomposition analysis was performed. The results run counter to the commonly accepted view that improvements in the tradable sector lead to inflation differentials between New and Old Member States. The model suggests that tradable productivity (and to some degree quality) improvements are only important in explaining movements in terms-of-trade. Therefore, although the HBS-like effect is consistent with the model, its results do not support the view that asymmetric productivity shocks originating in the tradable sector are of relevance for explaining inflation differentials between Poland and the eurozone. Quality factor also do not seem to matter. Instead, model results point to asymmetries in the nontradable sector. This conclusion matches that offered by Altissimo et al. (2005), who find that relative variations in productivity in the nontradable sector are the primary cause of price and inflation dispersion between the eurozone average and its member countries. Also, Rabanal and Tuesta (2006), using Bayesian methods, find that tradable technology shocks (and monetary policy shocks) are of little importance in moving RERs.

The importance of the nontradable productivity shock can be perhaps explained by the fact that the internal and external RER move in the same direction when the economy is hit by that shock. This is not the case when tradable productivity improvements occur. In fact, in the onset of the tradable productivity shock, internal and external real exchange rates move in the opposite direction diminishing overall RER volatility and significance of the tradable component in the RER movements. Nonetheless, even if it is true that the importance of the nontradable component could be overstated because of the model specifics, it is also true that for the reasonable parameter values, the model is able to explain around 70 percent of the variance of the Polish real exchange rate when the economy is hit by supply side shocks only. Also, this result is not at odds with the findings of the empirical analysis conducted in Section 3.2.1, which found that nontradable component could contribute to as much as 60 percent of the RER movements in Poland (i.e. the result shown for Betts and Kehoe (2006) price indices).

Of course, these results should be treated with caution as they are highly stylized and ignore the possibility of non-stationary shocks. However, it would not be unreasonable to assume that such permanent productivity shocks are anticipated (there is perfect foresight) and as such do not add to the volatility of the investigated variables.

CONCLUSIONS

In recent years there has been tremendous growth in interest, and in the literature addressing the full accession of the NMS into the EMU – in particular to their participation in the third stage of monetary union, which is intended to complete the project of creating a single European market. This dissertation contributes to this literature by proposing a definition of real convergence, which is based on real exchange rate dynamics. Because fluctuations in real exchange rates represent deviations from the PPP, this dissertation also contributes to the literature on PPP theory. Finally, by proposing a SOE-DSGE IRBC model of real exchange rate determinants for the NMSs of the EU, it fills a gap that has hitherto existed in the literature.

The analysis of real exchange rate dynamics was conducted on two levels: empirical and theoretical. On the empirical level, the scale of RER dynamics (with respect to the euro) in the NMSs of the EU was measured. Factors contributing to these dynamics were identified. On a theoretical level, and motivated by the empirical findings, variants of the SOE-DSGE-IRBC equilibrium model of RER determinants for a typical NMS of the EU were developed.

The relevance of RER dynamics as an indicator of real convergence in the context of the euro adoption was broadly discussed in the Introduction to this thesis and in Chapter 1. Given that the RER can be seen as an indicator of underlying economic conditions between the particular NMS and the eurozone, it was proposed that - in the eurozone candidate countries - real convergence could be measured in terms of real exchange rate volatility. Or more precisely, it was argued that the scale of RER volatility (against the euro) could be a useful measure of the degree of real convergence understood as the degree of symmetry between a particular NMS and the eurozone. This is because the lower the degree of real exchange rate volatility, the greater the extent of adjustment mechanisms at work other than the nominal exchange rate, and/or the lower the exposure of the NMS to asymmetric shocks, and/or the greater is the degree of symmetric monetary policy responses between the respective NMSs and the eurozone in response to symmetric shocks. Consequently, *a less volatile real exchange rate indicates less scope for monetary and exchange rate independence.* The advantage of using real exchange rate volatility as an indicator of real convergence is that it only relies on the assumption that *national price stability is desirable*, and that therefore the flexibility of the nominal exchange rate may be justified to avoid changes in the real exchange rate that entail inflation or deflation above or below the eurozone average.

To quantify RER volatility in the New and Old Member States of the EU, as well as to assess whether the NMSs are converging over time in real terms, in Chapter 1, a two-step variance analysis was conducted. In step one, the univariate variance analysis of real exchange rates in countries of interest was performed. To measure the degree of the RER volatility, the AR(p)-GARCH(p,q) econometric methodology was implemented. In step two, a bivariate variance analysis was done, using a BQ-SVAR methodology. It allowed for an accurate assessment of the degree of real convergence in countries of interests by separating and measuring the magnitude of real and nominal components in real exchange rate movements. Moreover, to the extent that giving up an independent monetary and exchange rate policy constitutes a cost of the euro adoption, the BQ-SVAR analysis also helped in evaluating the role of the nominal exchange rate in the NMSs in accommodating real asymmetric shocks.

The findings of Chapter 1 show that the univariate variance analysis performed in the chapter provides an accurate measure of RER volatility in the selected NMSs and OMSs, and thus a measure of real convergence. This is because the bivariate variance analysis conducted in this chapter revealed that the impact of nominal shocks in real exchange rates' movement at the 3-month forecast horizon in all the countries but Poland and the Czech Republic is minimal. Because, in Poland and the Czech Republic nominal disturbances are still somewhat significant, the true level of real convergence in these countries is in fact larger than suggested by the univariate variance analysis. Therefore, based on the developed definition of real convergence the following conclusions can be made. First and foremost, there are definite gains to the euro adoption by the NMSs of the EU. This is because, as the Blanchard and Quah (1989) variance decomposition showed, the nominal component of nominal exchange rate movements in counties in question (perhaps with the exception of

Slovakia, the most recent eurozone member) are not insignificant. Nevertheless, these shocks, on average, do not move real exchange rates and therefore are not destabilizing. Second, the analysis conducted showed that in all countries considered except for Slovenia (already a eurozone member), the nominal exchange rate plays a shock-stabilising role. In summary, the estimates show that based on the proposed definition of real convergence, more effort is needed in reducing idiosyncratic real shocks (with the exception of Slovenia[167] and Estonia) to lessen the costs of the eurozone membership. Immediate euro adoption is therefore perhaps not advisable. Instead more effort should be put into enhancing structural reforms.

From the policy point of view, if progress is to be made towards greater real convergence in the euro area, it is necessary to understand what generates the inflation differentials among the EMU members. To this extent, and given the findings of Chapter 1 that that most of the movements in the real exchange rate in the NMSs of the EU are real in nature, Chapter 2 and 3 developed variants of SOE-DSGE IRBC models of real exchange rate determinants for these countries[168].

There are two main challenges with building such models. The first challenge is related to the fact that international variables in the NMSs (such as terms-of-trade or real exchange rates) display a high degree of volatility relative to other macroeconomic aggregates. The second challenge is related to the fact that real exchange rates in the NMSs record persistent RER appreciation since the early 1990. Both of these features of the data for the NMSs are not easy to mirror in standard DSGE models. In fact, since volatile and persistent real exchange rates are also observed for developed countries, their dynamics are often referred to as 'puzzles' within the international economics literature. The reason why modelling RER appreciation is not easy relates to difficulties in capturing supply side factors responsible for RER appreciation in the NMSs – in particular quality and productivity changes. This is because, on one hand, the more traditional way of

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[167] As Slovenia is already in the eurozone, it can be said that – based on the proposed indicator – it was ready to give up its monetary and exchange rate policy and should benefit from euro adoption. On the other hand, Slovakia's entry into the euro area may have been premature.

[168] The reasons why the SOE-DSGE models developed in this work do not include nominal rigidities and monetary policy are elaborated in Section 2.2.

capturing quality changes in the DSGE framework is to include a R&D sector in model. As discussed, this approach is not appropriate for the NMSs where R&D expenditures are not significant and are mostly borne by multinational firms in their country of origin (see van de Klundert and Smulders (1999)). On the other hand, although, in the two-sector model, productivity improvements in the tradable sector should lead to currency appreciation as predicted by the HBS effect, in the standard DSGE models, a positive productivity shock causes a depreciation of external real exchange rates, which can more than offset an appreciation caused by the HBS effect (Benigno and Thoenissen (2003), Vilagi (2005)).

In this dissertation, the issue of real exchange rate volatility and its persistence were addressed within the international real business cycle models. This is because, as other research has shown (e.g. Søndergaard (2004)), there is nothing to be gained in terms of volatility and persistence from adding nominal rigidities to the standard DSGE model. Nevertheless, the basic SOE-DSGE IRBC model put forward in Chapter 2, although delivering a fairly persistent real exchange rate, underpredicted RER volatility, unless very low vales of elasticity of substitution between home and foreign traded goods were assumed. Therefore, in Chapter 3 new features were introduced. Nontradable goods, incomplete asset market structure and distribution trade costs were introduced to the expanded version of the SOE model. Introducing these new features did not change the model performance in terms of the RER persistence. However, its volatility increased significantly even for the more conventional levels of the trade elasticity (volatility essentially doubled even for the version of the model which excluded distribution services). Surprisingly, the expanded model did not perform so well in terms of matching the volatility of terms-of-trade. In this respect, the basic model proved better able to explain the empirical observations.

The SOE-DSGE IRBC models developed in Chapters 2 and 3 were also successful in generating the RER appreciation observed in the NMSs of the EU. It was shown that these models can be consistent with explanations of this appreciation both in terms of the quality factor (in the one and two-sector models) and the HBS effect (in the two-sector model). In particular, it was shown that, in the one-sector model with complete markets, quality changes lead to RER improvements. In the two-sector model with incomplete markets these improvements depend, however, on the value of the bond holding costs, i.e., they are possible when the costs are lower. The HBS-like effect in the two-sector SOE-DSGE IRBC model was shown to be possible provided higher bond holding costs and more conventional for the IRBC literature values for elasticity of substitution between home and foreign tradable goods are assumed. Although pricing-to-market (in the form of distributive trade costs) did contribute to the real exchange rate appreciation, it was not essential for it to happen (unlike in Vilagi (2005)). This result is important as, generally, two-sector DSGE models have trouble in preserving the HBS-like effect (Benigno and Theonissen (2003), Vilagi (2005)).

Given that the basic SOE model put forward in Chapter 2, unlike its expanded version of Chapter 3, was only able to roughly match the moments of the Polish data for very low levels of elasticity of substitution between home and foreign tradable goods, its findings contribute more to providing further insights into the long-standing theoretical 'puzzle' of RER volatility and its persistence, than to empirical policy work. Therefore, from the policy point of view, the conclusions based on the results obtained from simulations of the expanded model are of more relevance. The expanded model results show that relative variations in productivity in the *nontraded* sector are the main cause of price differentials between Poland and the euro area. This is in contrast to the two competing hypothesis that either productivity or quality improvements in the tradable sector are the main source of real exchange rate appreciation in these countries. Because of the specifics of the extended model of Chapter 3, it is possible that the significance of nontradable productivity shocks is overstated in the study (see conclusions to Chapter 3). Nevertheless, the findings match those of Altissimo et al. (2005) and Rabanal and Tuesta (2006) and support the empirical analysis conducted in Section 3.2.1, which showed that the nontradable component of RER movements could contribute to as much as 60% of the RER movements in Poland. Also, it was shown that for reasonable parameter values, the extended model is able to explain around 70 percent of the Polish real exchange rate variance when the economy is subjected to supply side shocks only.

Although, both the HBS and qualify factor hypotheses of RER appreciation are possible within the framework of the extended model of Chapter 3, the variance decomposition of Chapter 3 showed that neither of them appear to be the cause of RER appreciation in Poland. These hypotheses are also not supported by the findings of Chapter 1, where it was shown that in response to positive productivity shocks, real exchange rates depreciated in Poland and other NMSs. These findings lend support to another possible hypothesis which suggests that – consistent with Smaghi (2007) – RER appreciation observed the NMSs may be a result of overheating pressures. This may be a useful area of future research.

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ANNEX C.1. REAL EXCHANGE RATE DECOMPOSITION

The approach used to obtain the results shown in Figure 3.1 is described below.

The data for all the calculations is sourced from Eurostat. To calculate price indices for the variance decomposition in Graph 1 and 2, monthly data spanning from 1996M1 to 2007M2 is used. The data used in the decomposition presented in Graph 3 is of quarterly frequency and spans from 1995Q1 to 2008Q2. All the price indices have base year 2000 = 100. They are not seasonally adjusted.

First, the real exchange rate (RER_t) is decomposed into the traded component RER_t^T (i.e. nominal exchange rate deflated by tradable prices in the eurozone (EURO) and Poland), and the relative price component RER_t^{REL} (i.e. the relative price between the relative nontradable prices in eurozone and Poland):

$$RER_t = \ln(NER) + \ln(P_t^*) - \ln(P_t) = RER_t^T + RER_t^{REL} \qquad \text{(C1)}$$

(notice that the price index for Poland P_t and the eurozone P_t^{EURO} is a geometric weighted average of traded, $P_{T,t}$, and nontraded goods prices $P_{NT,t}$, respectively: $\ln(P_t) = (1-\alpha)\ln(P_{T,t}) + \alpha\ln(P_{NT,t})$, $\ln(P_t^{EURO}) = (1-\beta)\ln(P_{T,t}^{EURO}) + \beta\ln(P_{NT,t}^{EURO})$)

Second, the appropriate price indices are identified:

1. Engel's (1999) indices (i.e. Graph 1 in the main text)

Engel (1999) proposes the following definitions of RER_t^T and RER_t^{REL}:

$$RER_t^T = \ln(NER_t) + \ln(P_{T,t}^{EURO}) - \ln(P_{T,t}^{POL}) \qquad \text{(C2)}$$

where NER_t stands for the nominal exchange rate.

(C3) $$RER_t^{REL} = \beta(\ln(P_{NT,t}^{EURO}) - \ln(P_{T,t}^{EURO})) - \alpha(\ln(P_{NT,t}^{POL}) - \ln(P_{T,t}^{POL}))$$

where price indices $P_{T,t}$ and $P_{NT,t}$ are calculated from different sub-categories of the overall HICP index (CP00).

Services (SERV) and housing (Actual Rentals for Housing, CP041) are classified as nontradable and commodities as tradable (GOODS and IGOODS) [169].

(C4) $$P_{T,t} = \frac{\phi_1}{\phi_1 + \phi_2}(GOODS - IGOODS) + \frac{\phi_2}{\phi_1 + \phi_2}(IGOODS)$$

(C5) $$P_{NT,t} = \frac{\phi_3}{1 - \phi_1 - \phi_2}(SERV - CP041) + \frac{1 - \phi_1 - \phi_2 - \phi_3}{1 - \phi_1 - \phi_2}(CP041)$$

The weights for the particular sub-categories in the total price index are obtained by running a similar regression to that of Engel (1999, p.532):

(C6) $$\Delta(\text{CP00- CP041}) = \phi_1\Delta(\text{GOODS- IGOODS- CP041}) + \phi_2\Delta(\text{IGOODS-CP041}) + \phi_3\Delta(\text{SERV- CP041}) + \varepsilon_t$$

The estimates from running the regression (C6) show that the weights for the particular sub-categories are ϕ_1=0.2871, ϕ_2=0.4252, ϕ_3=0.1968.

2. HICP and PPI indices (i.e. Graph 2 in the main text)

Here, the same decomposition as in Engel (1999) is utilized, but $P_{T,t}$ is represented by the PPI indices and $P_{NT,t}$ by the HICP indices of currency zones in question, so that:

[169] These categories slightly differ from those used by Engel (compare Engel (1999, p. 532)).

(C7) $$RER_t^T = \ln(NER_t) + \ln(P_{PPI,t}^{EURO}) - \ln(P_{PPI,t}^{POL})$$

and

(C8) $$RER_t^{REL} = (\ln(P_{HICP,t}^{EURO}) - \ln(P_{PPI,t}^{EURO})) - (\ln(P_{HICP,t}^{POL}) - \ln(P_{PPI,t}^{POL}))$$

Using the PPI index for tradable prices has two disadvantages: first, some producer goods are most likely to be nontraded; and second, PPI data comes from the different survey than HICP data, which means that there may be measurement differences in the price of the same good (see Engel (1999) for details).

3. Betts and Khoe's (2006) indices (i.e. Graph 3 in the main text)

Betts and Kehoe (2006) use annual gross output data to construct internal relative prices RER_t^{NT}. In particular, they decompose gross output into primaries, manufactures, and services. They compute the traded fraction of the value of gross output in each of these three sectors (more then 10 percent of the gross output value has to be traded in order for the particular sector to be classified as traded, as in Gregorio et al. (1994)), and derive the nontraded RER_t^{NT} as a difference between RER_t (the aggregate price index for the country is equal to the nominal total gross output divided by real total gross output) and RER_t^T (defined as in (C2)) so that:

(C9) $$RER_t^{NT} = (\ln(P_{T,t}^{POL}) - \ln(P_t^{POL})) - (\ln(P_{T,t}^{EURO}) - \ln(P_t^{EURO}))$$

The advantage of this decomposition – as compared to that above – is that there is no need to directly measure the relative price of nontraded goods to capture their impact on real exchange rate determination.

Given data availability, in this chapter the data on quarterly Gross Value Added (GVA) is used instead of GDP. Unfortunately, as pointed out by Betts and Kehoe (2006), the GVA deflators are net of the value of intermediate goods and thus do not really measure production prices of sectoral outputs.

To obtain sectoral GVA (*DEF*) the economy is divided into two sectors: tradable and nontradable. The tradable sector comprises industry, less construction, agriculture, forestry and fishing – i.e. sections A, B, C, D and E of the NACE classification of economic activity. The nontadable sector consists of all other sectors (i.e., F-P).

$P_{T,t}$ is represented by the value added deflator for the tradable sector (*DEF_T*) of the economy. It is constructed by dividing the sectoral value added in current prices by the sectoral value added in constant prices. The sectoral weights (A, B, C, D, E) in the total value added are calculated using constant prices.

Then, RER_t^T and RER_t^{REL} reads as:

$$RER_t^T = \ln(NER_t) + \ln(P_{DEF\_T,t}^{EURO}) - \ln(P_{DEF\_T,t}^{POL}) \quad \text{(C10)}$$

$$RER_t^{REL} = (\ln(P_{DEF,t}^{POL}) - \ln(P_{DEF\_T,t}^{POL})) - (\ln(P_{DEF,t}^{EURO}) - \ln(P_{DEF\_T,t}^{EURO})) \quad \text{(C11)}$$

ANNEX C.2. PRICE INDEX AND DEMAND FUNCTIONS

Households solve two allocation problems. They need to decide how to allocate consumption between tradable and nontradable goods as well as how to allocate tradable consumption between home and foreign goods.

The CES price aggregator P_t (equation (3.7) in the main text) can be derived from the following household minimum expenditure problem:

$$\min_{C_t} P_t C_t$$

$$\text{s.t. } C_t = \left[(\gamma)^{\frac{1}{\varepsilon}} C_{T,t}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)^{\frac{1}{\varepsilon}} C_{NT,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{(C12)}$$

(C13) $$L = P_{NT,t}C_{NT,t} + P_{T,t}C_{T,t} + \mu_t\left[C_t - \left[(\gamma)^{\frac{1}{\varepsilon}}C_{T,t}{}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)^{\frac{1}{\varepsilon}}C_{NT,t}{}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}\right]$$

Note: Solving for the Lagrangian multiplier μ_t is equivalent to solving for the home goods price index P_t since μ_t is a proxy for the amount required to purchase one extra unit of consumption basket C_t (i.e., $\mu_t = P_t$).

First order conditions are:

(C14) $$\frac{\partial L}{\partial C_{\mathrm{NT,t}}}:\ P_{NT,t} - \mu_t(1-\gamma)C_t^{\frac{1}{1-\varepsilon}}\left(C_{NT,t}\right)^{\frac{-1}{\varepsilon}}$$

(C15) $$\frac{\partial L}{\partial C_{T,t}}:\ P_{T,t,} - \mu_t\gamma C_t^{\frac{1}{1-\varepsilon}}\left(C_{T,t}\right)^{\frac{-1}{\varepsilon}}$$

(C16) $$\frac{\partial L}{\partial \mu_t}:\ \left[(\gamma)^{\frac{1}{\varepsilon}}C_{T,t}{}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)^{\frac{1}{\varepsilon}}C_{NT,t}{}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} = C_t$$

(C14), (C15), (C16) can be re-written as:

(C14a) $$C_{NT,t} = (1-\gamma)\left(P_{NT,t}\right)^{-\varepsilon}\mu_t^{\varepsilon}C_t$$

(C15a) $$C_{T,t} = \gamma\left(P_{T,t}\right)^{-\varepsilon}\mu_t^{\varepsilon}C_t$$

(C16a) $$\left[(\gamma)^{\frac{1}{\varepsilon}}C_{T,t}{}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma)^{\frac{1}{\varepsilon}}C_{NT,t}{}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} = C_t = 1$$

where (C14a) and (C15a) are final demand functions for nontradable and tradable consumption goods.

Now, substituting (C14a) and (C15a) into (C16a), it is possible to solve for μ_t and thus P_t (which is the equation (3.7) in the main text). The CES price aggregator $P_{T,t}$ (see equation (3.8) in the main text) can be derived analogically (see also Annex B.1).

Individual Demand Functions

Individual demand functions for the representative consumer *s* are obtained from the optimal allocation of expenditure across H, NT and F goods.

$$\text{(C17)} \qquad \begin{aligned} &\min_{C_{j,t}} \int_0^n P_{j,t}(j) C_{j,t}(j) di \\ &s.t.\ C_{j,t} \equiv \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma_j}} \int_0^n C_{j,t}(j)^{\frac{\sigma_j - 1}{\sigma_j}} dj \right]^{\frac{\sigma_j}{\sigma_j - 1}} \end{aligned} \qquad j = H, NT$$

$$\text{(C18)} \qquad L = \int_0^n P_{j,t}(j) C_{j,t}(j) dj \quad + \mu_{j,t} \left[C_{j,t} - \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma_j}} \int_0^n C_{j,t}(j)^{\frac{\sigma_j - 1}{\sigma_j}} dj \right]^{\frac{\sigma_j}{\sigma_j - 1}} \right]$$

First order conditions are:

$$\text{(C19)} \qquad \frac{\partial L}{\partial C_{j,t}(j)} : \ \mathrm{C}_{j,t}(j) = \frac{1}{n} \mu^{\sigma_j} C_{j,t} \left(P_{t,j}(j) \right)^{-\sigma_j}$$

$$\text{(C20)} \qquad \frac{\partial L}{\partial \mu_t} : C_{j,t} = \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma_j}} \int_0^n C_{j,t}(j)^{\frac{\sigma_j - 1}{\sigma_j}} dj \right]^{\frac{\sigma_j}{\sigma_j - 1}}$$

To solve for $\mu_{j,t}$ it is enough to substitute (C20) into (C19):

$$\text{(C21)} \qquad \mu_{j,t} = \left[\left(\frac{1}{n} \right) \int_0^n P_{j,t}(j)^{1-\sigma_j} dj \right]^{\frac{1}{1-\sigma_j}} = P_{j,t}$$

So that the individual demand for the unique good $C_{j,t}(j)$ can be written as:

(C22) $$C_{j,t}(j) = \frac{1}{n}\left(\frac{P_{j,t}(j)}{P_{j,t}}\right)^{-\sigma_j} C_{j,t}$$

Individual demand for the unique good $C_{F,t}(f)$ can be obtained in the similar manner, i.e. by solving the following household's minimum expenditure problem:

(C23) $$\min_{C_{F,t}} \int_n^1 P_F(f) C_F(f) df$$

$$s.t.\ C_{F,t} \equiv \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma_F}} \int_n^1 C_{F,t}(f)^{\frac{\sigma_F - 1}{\sigma_F}} df\right]^{\frac{\sigma_F}{\sigma_F - 1}}$$

(C24) $$L = \int_n^1 P_F(f) C_F(f) df \quad + \mu_{F,t}\left[C_{F,t} - \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\sigma_F}} \int_n^1 C_{F,t}(f)^{\frac{\sigma_F - 1}{\sigma_F}} df\right]^{\frac{\sigma_F}{\sigma_F - 1}}\right]$$

So that:

(C25) $$C_{F,t}(f) = \frac{1}{1-n}\left(\frac{P_{F,t}(f)}{P_{F,t}}\right)^{-\sigma} C_{F,t}$$

To obtain equation (3.18) from the main text, it is enough to substitute (C14a) into (C22). To obtain equations (3.19) and (3.20) of the main text it is however necessary to derive demand functions for home and foreign tradable goods from the following minimization problem:

(C26) $$\min_{C_{T,t}} P_{T,t} C_{T,t}$$

$$s.t.\ C_{T,t} = \left[(\lambda)^{\frac{1}{\phi}} C_{H,t}^{\frac{\phi - 1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}} C_{F,t}^{\frac{\phi - 1}{\phi}}\right]^{\frac{\phi}{\phi - 1}}$$

$$L = P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + \mu_{T,t}\left[C_{T,t} - \left[(\lambda)^{\frac{1}{\phi}} C_{H,t}^{\frac{\phi-1}{\phi}} + (1-\lambda)^{\frac{1}{\phi}} C_{F,t}^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} \right]$$

They are respectively:

(C27) $$C_{H,t} = \lambda\left(\frac{P_{H,t}}{P_{T,t}}\right)^{-\phi} C_{T,t}$$

(C28) $$C_{F,t} = (1\text{-}\lambda)\left(\frac{P_{F,t}}{P_{T,t}}\right)^{-\phi} C_{T,t}$$

Substitution of (C15a) into (C27) and (C28) yields:

(C29) $$C_{H,t} = \lambda\gamma\left(\frac{P_{H,t}}{P_{T,t}}\right)^{-\phi} \left(\frac{P_{T,t}}{P_t}\right)^{-\varepsilon} C_t$$

(C30) $$C_{F,t} = (1\text{-}\lambda)\gamma\left(\frac{P_{F,t}}{P_{T,t}}\right)^{-\phi} \left(\frac{P_{T,t}}{P_t}\right)^{-\varepsilon} C_t$$

Finally, substituting (C29) and (C30) into (C22) and (C25), respectively, brings equations (3.19) and (3.20) .

ANNEX C.3. FOREIGN COUNTRY TRADABLE OUTPUT

The production function for the tradable output $Y^{*}_{F,t}(f)$ for a large economy takes a CES form, as is the case of the SOE. However, given that SOE does not affect the large country, foreign output comprises of the domestic value added $VA^{*}_{F,t}$ and intermediate domestic input D^{*}_{t}.

(C31) $$Y^{*}_{F,t}(f) = Y^{*}_{F,t} = \left[\upsilon_F^{\frac{1}{\mu_F}} VA^{*\,\frac{\mu_F-1}{\mu_F}}_{F,t} + (1-\upsilon_F)^{\frac{1}{\mu_F}} D_t^{*\,\frac{\mu_F-1}{\mu_F}} \right]^{\frac{\mu_F}{\mu_F-1}}$$

Domestic value added for the large economy evolves in accordance with the standard Cobb-Douglas production function of primary factors, capital $K^*_{F,t}$ and labour $N^*_{F,t}$:

(C32) $$VA^*_{F,t} = A^*_{F,t}(K^*_{F,t-1})^{\alpha_F}(N^*_{F,t})^{1-\alpha_F}$$

From the cost minimisation similar to that described by the equation (3.43) for the SOE, the following ratio is obtained:

(C33) $$\frac{R^*_{F,t}K^*_{F,t-1}}{\alpha_F} = \frac{W^*_{F,t}N^*_{F,t}}{1-\alpha_F}$$

as well as a functional form determining demand for the domestic intermediate good D^*_t:

(C34) $$\frac{P^*_{D,t}}{P^{*P}_{F,t}} = \frac{MC^*_{F,t}}{P^{*P}_{F,t}}(1-\upsilon_F)^{\frac{1}{\mu_F}}\left(\frac{Y^*_{F,t}(f)}{D^*_t}\right)^{\frac{1}{\mu_F}}$$

where $P^*_{D,t}$ is the foreign currency price of the domestic intermediate good and $MC^*_{F,t}$ is the marginal cost of production in the foreign tradable sector.

Foreign demand for the intermediate imported good is not modelled explicitly. It is assumed that the following *ad hoc* equation determines the demand for this good (i.e., it resembles the SOE demand equation for imported intermediate good):

(C35) $$\frac{P^*_{M,t}}{P^{*P}_{F,t}} = \frac{MC^*_{F,t}}{P^{*P}_{F,t}}(1-\upsilon_F)^{\frac{1}{\mu_F}}\left(\frac{Y^*_{F,t}(f)}{M^*_t}\right)^{\frac{1}{\mu_F}}$$

where $P^*_{M,t}$ is the foreign currency price of the imported intermediate good, and M^*_t represents the quantity. υ_F and μ_F are assumed to be the same as for the domestic economy.

$P^*_{M,t}$ is at the world price level and also represents the purchase price of foreign intermediate goods paid by domestic importers. It is given exogenously. Thus, in the symmetric equilibrium, $M^*_t = M_t$.

ANNEX C.4. DEMAND ELASTICITY AND DISTRIBUTION COSTS

Equation (3.21) from the main text can be re-written as:

$$\text{(C36)} \qquad \left(\frac{P_{F,t}}{P_{H,t}}\right) = \frac{P^P_{F,t} + \zeta P_{NT,t}}{P^P_{H,t} + \zeta P_{NT,t}} = \left(\frac{1-\lambda}{\lambda}\frac{C_{H,t}}{C_{F,t}}\right)^{\frac{1}{\phi}} = \left(\frac{\omega}{1-\omega}\frac{C_{H,t}}{C_{F,t}}\right)^{\frac{1}{\phi}} = G(t)$$

Now log-linearizing the equality G(t), i.e., $G\left(P^P_{H,t}, P^P_{F,t}, P_{NT,t}\right) = f(C_{H,t}, C_{F,t})$ leads to

(C37)

$$\frac{P^P_{F,t=0}}{P_{H,t=0}}\left(\widehat{P}^P_{F,t} - \widehat{P}^P_{H,t}\right) = \frac{P_{F,t=0} - \zeta P_{NT,t=0}}{P_{H,t=0}}\left(\widehat{P}^P_{F,t} - \widehat{P}^P_{H,t}\right) \cong \frac{G_{t=0}}{\phi}\left(\widehat{C}_{H,t} - \widehat{C}_{F,t}\right)$$

Since in the steady-state

$P_{H,t=0} = P_{F,t=0} = P_{T,t=0}$ and thus $\mathrm{G}_{t=0} = 1$

The above comes down to

$$\text{(C38)} \qquad \left(1 - \zeta\frac{P_{NT,t=0}}{P_{H,t=0}}\right)\left(\widehat{P}^P_{F,t} - \widehat{P}^P_{H,t}\right) = \left(1-\mu^D\right)\left(\widehat{P}^P_{F,t} - \widehat{P}^P_{H,t}\right) \cong \frac{1}{\phi}\left(\widehat{C}_{H,t} - \widehat{C}_{F,t}\right)$$

and

$$\text{(C39)} \qquad \left(\widehat{P}^P_{F,t} - \widehat{P}^P_{H,t}\right) \cong \frac{1}{\phi\left(1-\mu^D\right)}\left(\widehat{C}_{H,t} - \widehat{C}_{F,t}\right) \text{ as in Corsetti et al. (2008)}$$

where $\Omega = \phi\left(1-\mu^{D}\right)$ is the price elasticity of imports (or elasticity of substitution between H and F tradable goods adjusted for the presence of distribution costs).

Recall that terms-of-trade and the producer level equals the price ratio of the imported and domestic tradable good at the wholesale level, $T_t^P = \frac{P_{F,t}^P}{P_{H,t}^P}$, which in a log linear form is

$$\text{(C40)} \qquad \widehat{T}_t^P = \widehat{P}_{F,t}^P - \widehat{P}_{H,t}^P$$

So that

$$\text{(C41)} \qquad \widehat{T}_t^P \cong \frac{1}{\phi\left(1-\mu^{D}\right)}\left(\widehat{C}_{H,t} - \widehat{C}_{F,t}\right)$$

Therefore, as discussed in Corsetti et al. (2008), increasing distribution margins μ^{D} lowers the implied price elasticity of elasticity of substitution between H and F tradable goods Ω. Moreover, for the terms-of-trade to appreciate, either a positive productivity shock has to induce an increase in consumption of foreign goods (i.e. via wealth effect) which is larger than the increase in consumption of home tradable goods, or distribution margins would have to be larger than 100.

ANNEX C.5. OPTIMAL PRICING PROBLEM FOR THE DOMESTIC TRADABLE FIRM

The tradable goods' producers' profit maximization problem (3.49) can be re-written as:

$$\text{(C42)}\quad \max_{P^P_{H,t}(h),P^{*P}_{H,t}(h)} \left\{ \begin{array}{l} (1-\tau_H)\left(\frac{P^P_{H,t}(h)+\zeta P_{NT,t}}{P_{H,t}}\right)^{-\sigma_H} \frac{P^P_{H,t}(h)}{P_t} Y^d_{H,t} + \\ -\frac{MC_{H,t}}{P_t}\left(\frac{P^P_{H,t}(h)+\zeta P_{NT,t}}{P_{H,t}}\right)^{-\sigma_H} Y^d_{H,t} \\ +\left(Q_t \left(\frac{P^{*P}_{H,t}(h)+\zeta P^*_{NT,t}}{P^*_{H,t}}\right)^{-\sigma_H} \frac{P^{*P}_{H,t}(h)}{P^*_t} Y^{*d}_{H,t} - \frac{MC_{H,t}}{P_t}\left(\frac{P^{*P}_{H,t}(h)+\zeta P^*_{NT,t}}{P^*_{H,t}}\right)^{-\sigma_H} Y^{*d}_{H,t}\right) \end{array} \right\}$$

$$\text{(C43)}\quad \begin{array}{l} \frac{\partial}{\partial \overline{P_{H,t}(h)}}: \quad (1-\tau_H)(-\sigma_H)\left(\frac{P^P_{H,t}(h)+\zeta P_{NT,t}}{P_{H,t}}\right)^{-\sigma_H-1} \frac{P^P_{H,t}(h)}{P_{H,t}P_t} Y^d_{H,t} + \\ + \ (1-\tau_H)\left(\frac{P^P_{H,t}(h)+\zeta P_{NT,t}}{P_{H,t}}\right)^{-\sigma_H} \frac{1}{P_t} Y^d_{H,t} + \\ + \ \sigma_H \frac{1}{P_{H,t}}\left(\frac{P^P_{H,t}(h)+\zeta P_{NT,t}}{P_{H,t}}\right)^{-\sigma_H-1} \frac{MC_{H,t}}{P_t} Y^d_{H,t} = 0 \end{array}$$

which can be re-witten as:

$$\text{(C44)}\quad \begin{array}{l} \frac{\partial}{\partial p_{H,t}(i)}: (1-\tau_H)(-\sigma_H)\frac{\left(P^P_{H,t}(h)+\zeta P_{NT,t}\right)^{-\sigma_H}}{\left(P_{H,t}\right)^{-\sigma_H}}\left(\frac{P_{H,t}}{P^P_{H,t}(h)+\zeta P_{NT,t}}\right) * \\ \frac{P^P_{H,t}(h)}{P_{H,t}P_t} Y^d_{H,t} + (1-\tau_H)\frac{\left(P^P_{H,t}(h)+\zeta P_{NT,t}\right)^{-\sigma_H}}{\left(P_{H,t}\right)^{-\sigma_H}} \frac{1}{P_t} Y^d_{H,t} + \\ +\sigma_H \frac{1}{P_{H,t}} \frac{\left(P^P_{H,t}(h)+\zeta P_{NT,t}\right)^{-\sigma_H}}{\left(P_{H,t}\right)^{-\sigma_H}}\left(\frac{P_{H,t}}{P^P_{H,t}(h)+\zeta P_{NT,t}}\right)\frac{MC_{H,t}}{P_t} Y^d_{H,t} = 0 \end{array}$$

and simplified to (i.e., $Y^d_{H,t}$ and $P_{H,t}$ cancels out):

$$\text{(C45)}\quad \begin{array}{l} \frac{\partial}{\partial P_{H,t}(h)}: (1-\tau_H)(-\sigma_H)\frac{P^P_{H,t}(h)}{P_t} + (1-\tau_H)\left(P^P_{H,t}(h)+\zeta P_{NT,t}\right)\frac{1}{P_t} + \\ +\sigma_H \frac{MC_{H,t}}{P_t} = 0 \end{array}$$

Now, re-arranging the above, it can be shown that $P_{H,t}^{P}(h)$ (in real terms) is a function of $MC_{H,t}$ and $P_{NT,t}$:

(C46) $$\frac{P_{H,t}^{P}(h)}{P_t} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\frac{MC_{H,t}}{P} + \frac{1}{\sigma_H - 1}\frac{\zeta P_{NT,t}}{P_t}$$

(C47) $$\begin{aligned}\frac{\partial}{\partial P_{H,t}^{*P}(h)}: \quad & Q_t(1-\tau_H)(-\sigma_H)\left(\frac{P_{H,t}^{*P}(h)+\zeta P_{NT,t}^{*}}{P_{H,t}^{*}}\right)^{-\sigma_H - 1}\frac{P_{H,t}^{*P}(h)}{P_{H,t}^{*}P_t^{*}}Y_{H,t}^{*d} + \\ & + Q_t(1-\tau_H)\left(\frac{P_{H,t}^{*P}(h)+\zeta P_{NT,t}^{*}}{P_{H,t}^{*}}\right)^{-\sigma_H}\frac{1}{P_t^{*}}Y_{H,t}^{*d} + \\ & + \sigma_H\frac{1}{P_{H,t}^{*}}\left(\frac{P_{H,t}^{*P}(h)+\zeta P_{NT,t}^{*}}{P_{H,t}^{*}}\right)^{-\sigma_H - 1}\frac{MC_{H,t}}{P_t}Y_{H,t}^{*d} = 0\end{aligned}$$

which can be simplified to:

(C48) $$\frac{\partial}{\partial \overline{P_{H,t}^{*}(i)}}: Q_t(1-\tau_H)(-\sigma_H + 1)\overline{P_{H,t}^{*}(i)} = -\sigma_H P_t^{*}\frac{MC_{H,t}}{P_t} - Q_t(1-\tau_H)\zeta P_{NT,t}^{*}$$

and re-arragned to:

(C49) $$\frac{\overline{P_{H,t}^{*}(i)}}{P_t^{*}} = \frac{\sigma_H}{(1-\sigma_H)}\frac{1}{(1-\tau_H)}\frac{1}{Q_t}\frac{MC_{H,t}}{P_t} + \frac{1}{(1-\sigma_H)}\frac{\zeta P_{NT,t}^{*}}{P_t^{*}}$$

Recall that

$$\frac{P_{NT,t}}{P_t} = \frac{\sigma_{NT}}{\sigma_{NT} - 1}\frac{1}{1-\tau_{NT}}\frac{MC_t^{NT}}{P_t} = mk_{NT}mc_t^{NT}$$

where $mk_{NT} = \frac{\sigma_{NT}}{\sigma_{NT} - 1}\frac{1}{1-\tau_{NT}}$

so finally:

(C50)

$$\frac{P_{H,t}^{P}(h)}{P_t} = \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\frac{MC_{H,t}}{P} + \frac{\zeta}{\sigma_H - 1} mk_{NT}\frac{MC_{NT,t}}{P_t} =$$

$$= \frac{\sigma_H}{\sigma_H - 1}\frac{1}{1-\tau_H}\left(1 + \frac{\zeta(1-\tau_H)}{\sigma_H - 1} mk_{NT}\frac{MC_{NT,t}}{MC_{H,t}}\right)\frac{MC_{H,t}}{P}$$

and

(C51)

$$\frac{P_{H,t}^{*P}(h)}{P_t^*} = \frac{\sigma_H}{(1-\sigma_H)}\frac{1}{(1-\tau_H)}\frac{1}{Q_t}\frac{MC_{H,t}}{P_t} + \frac{1}{(1-\sigma_H)}\frac{\zeta P_{NT,t}^*}{P_t^*} =$$

$$\frac{\sigma_H}{(1-\sigma_H)}\frac{1}{(1-\tau_H)}\frac{1}{Q_t}\left(1 + \frac{\zeta(1-\tau_H)}{(1-\sigma_H)} mk_{NT}\frac{MC_{NT,t}^*}{MC_{H,t}}\right)\frac{MC_{H,t}}{P_t}$$

$$Q_t\frac{P_{H,t}^{*P}(h)}{P_t^*} = \frac{\sigma_H}{(1-\sigma_H)}\frac{1}{(1-\tau_H)}\left(1 + \frac{\zeta(1-\tau_H)}{(1-\sigma_H)} mk_{NT}\frac{MC_{NT,t}^*}{MC_{H,t}}\right)\frac{MC_{H,t}}{P_t}$$

ANNEX C.6. REAL EXCHANGE RATE: LOG-LINEARIZATION

Log-linearization is obtained in a standard way, by using a first order Taylor approximation around the steady state, i.e. it can be shown that the log-linear form of:

$$g(Z_t) = f(X_t, Y_t)$$

where X_t, Y_t and Z_t are strictly positive variables

is:

$$\left[g^{'}(Z)Z(0)z_t\right] = \left[f_1(X(0),\ Y(0))X(0)x_t\ + f_2(X(0),\ Y(0))Y(0)\ y_t\right]$$

where $X(0), Y(0), Z(0)$ are time 0 (steady-state) values

In order to log-linearize the real exchange rate equation <u>without</u> distribution services:

$$Q_t = \frac{P_t^*}{P_t} = \frac{[\lambda^*({P^*}_{H,t})^{1-\phi} + (1-\lambda^*)({P^*}_{F,t})^{1-\phi}]^{\frac{1}{1-\phi}}}{[\lambda(P_{H,t})^{1-\phi} + (1-\lambda)(P_{F,t})^{1-\phi}]^{\frac{1}{1-\phi}}} \frac{\left[\gamma^* + (1-\gamma^*)\left(\frac{{P^*}_{NT,t}}{{P^*}_{T,t}}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}}{\left[\gamma + (1-\gamma)\left(\frac{P_{NT,t}}{P_{T,t}}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}}$$

the following steps are taken:

Let

$$A = [\underbrace{\lambda^*({P^*}_{H,t})^{1-\phi} + (1-\lambda^*)({P^*}_{F,t})^{1-\phi}}_{A_1}]^{\frac{1}{1-\phi}}$$

$$X = [\underbrace{\lambda(P_{H,t})^{1-\phi} + (1-\lambda)(P_{F,t})^{1-\phi}}_{X_1}]^{\frac{1}{1-\phi}}$$

and

$$B = \left[\underbrace{\gamma^* + (1-\gamma^*)\left(\frac{{P^*}_{NT,t}}{{P^*}_{T,t}}\right)^{1-\varepsilon}}_{B_1}\right]^{\frac{1}{1-\varepsilon}}$$

$$Y = \left[\underbrace{\gamma + (1-\gamma)\left(\frac{P_{NT,t}}{P_{T,t}}\right)^{1-\varepsilon}}_{Y_1}\right]^{\frac{1}{1-\varepsilon}}$$

and $\quad P = AB = A_1^{\frac{1}{1-\phi}} B_1^{\frac{1}{1-\varepsilon}}$

$$Z = XY = X_1^{\frac{1}{1-\phi}} Y_1^{\frac{1}{1-\varepsilon}}$$

<u>Partial derivatives with respect to foreign variables:</u>

$$\frac{\partial A}{\partial P_{H,t}^*} : \lambda^* A A_1^{-1} P_{H,t}^{*-\phi} \qquad \frac{\partial A}{\partial P_{F,t}^*} : (1-\lambda^*) A A_1^{-1} P_{F,t}^{*-\phi}$$

$$\frac{\partial B}{\partial P_{NT,t}^*} : (1-\gamma^*) B B_1^{-1} \left(\frac{P_{NT,t}^*}{P_{T,t}^*}\right)^{-\varepsilon} \frac{1}{P_{T,t}^*} \qquad \frac{\partial B}{\partial P_{T,t}^*} : -(1-\gamma^*) B B_1^{-1} \left(\frac{P_{NT,t}^*}{P_{T,t}^*}\right)^{-\varepsilon} \frac{P_{NT,t}^*}{P_{T,t}^{*2}}$$

$$\frac{\partial P}{\partial P_{H,t}^*} : \frac{\partial A}{\partial P_{H,t}^*} B = \lambda^* A A_1^{-1} B P_{H,t}^{*-\phi} \qquad \frac{\partial P}{\partial P_{F,t}^*} : \frac{\partial A}{\partial P_{F,t}^*} B = (1-\lambda^*) A A_1^{-1} B P_{F,t}^{*-\phi}$$

$$\frac{\partial P}{\partial P_{NT,t}^*} : \frac{\partial B}{\partial P_{NT,t}^*} A = (1-\gamma^*) B B_1^{-1} A \left(\frac{P_{NT,t}^*}{P_{T,t}^*}\right)^{-\varepsilon} \frac{1}{P_{T,t}^*}$$

$$\frac{\partial P}{\partial P^*_{T,t}} : \frac{\partial B}{\partial P^*_{T,t}} A = -(1-\gamma^*) BB_1^{-1} A \left(\frac{P^*_{NT,t}}{P^*_{T,t}} \right)^{-\varepsilon} \frac{P^*_{NT,t}}{P^{*2}_{T,t}}$$

Partial derivatives with respect to home variables:

$$\frac{\partial X}{\partial P_{H,t}} : \lambda XX_1^{-1} P_{H,t}^{-\phi} \qquad \frac{\partial X}{\partial P_{F,t}} : (1-\lambda) XX_1^{-1} P_{F,t}^{-\phi}$$

$$\frac{\partial Y}{\partial P_{NT,t}} : (1-\gamma) YY_1^{-1} \left(\frac{P_{NT,t}}{P_{T,t}} \right)^{-\varepsilon} \frac{1}{P_{T,t}} \qquad \frac{\partial Y}{\partial P_{T,t}} : -(1-\gamma) YY_1^{-1} \left(\frac{P_{NT,t}}{P_{T,t}} \right)^{-\varepsilon} \frac{P_{NT,t}}{P_{T,t}^2}$$

$$\frac{\partial Z}{\partial P_{H,t}} : \frac{\partial X}{\partial P_{H,t}} Y = \lambda XX_1^{-1} Y P_{H,t}^{-\phi} \qquad \frac{\partial Z}{\partial P_{F,t}} : \frac{\partial Z}{\partial P_{F,t}} BY = (1-\lambda) XX_1^{-1} Y P_{F,t}^{-\phi}$$

$$\frac{\partial Z}{\partial P_{NT,t}} : \frac{\partial Y}{\partial P_{NT,t}} X = (1-\gamma) YY_1^{-1} X \left(\frac{P_{NT,t}}{P_{T,t}} \right)^{-\varepsilon} \frac{1}{P_{T,t}}$$

$$\frac{\partial Z}{\partial P_T} : \frac{\partial Y}{\partial P_T} X = -(1-\gamma) YY_1^{-1} X \left(\frac{P_{NT}}{P_T} \right)^{-\varepsilon} \frac{P_{NT}}{P_T^2}$$

Notice:

LHS $= f(P_{H,t}, P_{F,t}, P_{NT,t}, P_{T,t}, P^*_{H,t}, P^*_{F,t}, P^*_{NT,t}, P^*_{T,t}) = \dfrac{A(P^*_{H,t}, P^*_{F,t}) B(P^*_{NT,t}, P^*_{T,t})}{X(P_{H,t}, P_{F,t}) Y(P_{NT,t}, P_{T,t})}$

RHS = $g(P_t, P_t^*)$

$$\left. \frac{\partial f}{\partial P^*_{H,t}} \right|_{t=0} : \frac{\partial A}{\partial P^*_H} \frac{B}{XY} = \frac{\lambda^* AA_1^{-1} BP_H^{*-\phi}}{XY} = \frac{\lambda^*}{P_F}$$

$$\left. \frac{\partial f}{\partial P^*_F} \right|_{t=0} : \frac{\partial A}{\partial P^*_F} \frac{B}{XY} = \frac{(1-\lambda^*) AA_1^{-1} BP_F^{*-\phi}}{XY} = \frac{(1-\lambda^*)}{P_F}$$

$$\left.\frac{\partial f}{\partial P_{NT}^*}\right|_{t=0} : \frac{\partial B}{\partial P_{NT}^*}\frac{A}{XY} = \frac{(1-\gamma^*)BB_1^{-1}A\left(\frac{P_{NT}^*}{P_T^*}\right)^{-\varepsilon}}{XYP_T^*} = \frac{(1-\gamma^*)P_F^*}{P_F P_T^*}$$

$$\left.\frac{\partial f}{\partial P_T^*}\right|_{t=0} : \frac{\partial B}{\partial P_T^*}\frac{A}{XY} = -\frac{(1-\gamma^*)BB_1^{-1}A\left(\frac{P_{NT,t}^*}{P_{T,t}^*}\right)^{-\varepsilon} P_{NT}^* P_F^*}{XYP_T^{*2}} = -\frac{(1-\gamma^*)P_F^*}{P_F P_T^*}$$

$$\left.\frac{\partial f}{\partial P_H}\right|_{t=0} : \frac{\partial X}{\partial P_H}\frac{AB}{Y}\left(-\frac{1}{X^2}\right) = -\frac{\lambda X_1^{-1}ABP_H^{-\phi}}{XY} = -\frac{\lambda P_F^*}{P_F^2}$$

$$\left.\frac{\partial f}{\partial P_F}\right|_{t=0} : -\frac{\partial X}{\partial P_F}\frac{AB}{YX^2} = -\frac{(1-\lambda)X_1^{-1}ABP_F^{-\phi}}{YX} = -\frac{(1-\lambda^*)P_F}{P_F^2}$$

$$\left.\frac{\partial f}{\partial P_{NT,t}}\right|_{t=0} : \frac{\partial Y}{\partial P_{NT,t}}\frac{AB}{X}\left(-\frac{1}{Y^2}\right) = -\frac{(1-\gamma)YY_1^{-1}AB\left(\frac{P_{NT,t}}{P_{T,t}}\right)^{-\varepsilon}}{XY^2 P_{T,t}} = -\frac{(1-\gamma)P_{F,t}^*}{P_{F,t}P_{T,t}}$$

$$\left.\frac{\partial f}{\partial P_T}\right|_{t=0} : -\frac{\partial Y}{\partial P_T}\frac{AB}{XY^2} = -\frac{(1-\gamma)Y_1^{-1}AB\left(\frac{P_{NT}}{P_T}\right)^{-\varepsilon} P_{NT}}{XYP_T^2} = -\frac{(1-\gamma)P_F^*}{P_F P_T}$$

Now, log-linearization of the RHS is:

$$\left(\begin{array}{l} \left.\frac{\partial f}{\partial P_{Ht}^*}\right|_{t=0} P_{H,t}^*(0)p_{H,t}^* + \left.\frac{\partial f}{\partial P_{F,t}^*}\right|_{t=0} P_{F,t}^*(0)p_{F,t}^* + \left.\frac{\partial f}{\partial P_{NT,t}^*}\right|_{t=0} P_{NT,t}^*(0)p_{NT,t}^* \\ + \left.\frac{\partial f}{\partial P_{T,t}^*}\right|_{t=0} P_{T,t}^*(0)p_{T,t}^* + \left.\frac{\partial f}{\partial P_{H,t}}\right|_{t=0} P_{H,t}(0)p_{H,t} + \left.\frac{\partial f}{\partial P_{F,t}}\right|_{t=0} P_{F,t}(0)p_{F,t} \\ + \left.\frac{\partial f}{\partial P_{NT,t}}\right|_{t=0} P_{NT,t}(0)p_{NT,t} + \left.\frac{\partial f}{\partial P_T}\right|_{t=0} P_{T,t}(0)p_{T,t} \end{array}\right) =$$

$$= \left(\lambda - \lambda^*\right)\left(p_{F,t} - p_{H,t}\right) + (1-\gamma^*)(p_{NT,t}^* - p_{T,t}^*) + (\gamma - 1)(p_{NT,t} - p_{T,t})$$

To log-linearize the LHS of the equation, since it contains only multiplicative terms, one can use a faster procedure:

$$LHS = \frac{P_t^*}{P_t} = \frac{P_t^* / P^*(0)}{P_t / P(0)} = \log\left(\frac{P_t^* / P^*(0)}{P_t / P(0)}\right) = \log(P_t^*) - \log(P^*(0)) - (\log(P_t\ ) - \log(P(0))$$

$$LHS = p_t^* - p_t$$

Since LHS=RHS, we have

$$\widehat{p_t}^* - \widehat{p_t} = \left(\lambda - \lambda^*\right)\left(\widehat{p_{F,t}} - \widehat{p_{H,t}}\right) + (1-\gamma^*)(\widehat{p_{NT,t}}^* - \widehat{p_{T,t}}^*) + (\gamma - 1)(\widehat{p_{NT,t}} - \widehat{p_{T,t}})$$

Or with the symmetric home bias in both countries, i.e., $\lambda^* = (1-\lambda)$, and further assuming $\gamma = \gamma^*$:

$$\text{(C52)} \qquad \widehat{p_t}^* - \widehat{p}_t = (2\lambda - 1)\left(\widehat{p}_{F,t} - \widehat{p}_{H,t}\right) + (1-\gamma)\begin{pmatrix} \left(\widehat{p}_{T,t} - \widehat{p}_{NT,t}\right) + \\ -\left(\widehat{p}^*_{T,t} - \widehat{p}^*_{NT,t}\right) \end{pmatrix}$$

Note that within this (well known) decomposition, deviations from PPP can occur because of the home bias channel, because H and F goods are at least imperfect substitutes, or because of the differences in the relative price of tradables to nontradables between the countries $\left(\left(\hat{p}_T - \hat{p}_{NT}\right) \neq \left(\widehat{p}^*_T - \widehat{p}^*_{NT}\right)\right)$. Moreover, unless different elasticities of demand for the same good across countries are allowed for, the LOOP holds in the model without distribution services.

ANNEX C.7. STEADY-STATE CHARACTERIZATION

The non-stochastic steady-state is defined with a zero inflation rate. The small open economy is presented as a limiting case of a two-country symmetric model, i.e. it is assumed that n=0 and home bias $\lambda = (1-\omega)$. Unless indicated otherwise, for steady-state values subscript t is dropped. The steady-state is solved analytically.

In the steady-state, all shocks are constant and normalized to one:

$$A_{NT} = A_H = \chi_{NT}^{\varphi-1} = \chi_T^{\varphi-1} = 1$$

Gross steady-state domestic real interest rate is:

$$(1+r) = 1/\beta$$

Sectoral rental rates for capital are:

$$r_K^{\ j} = \frac{1}{\beta} - (1-\delta) = r + \delta$$

Capital accumulation evaluated at the steady-state yields the investment to capital ratio in both sectors equal to its rate o depreciation:

$$\frac{I^j}{K^j} = \delta$$

Steady-state labor supply L is fixed to be 0.3 (a standard value in the literature), sectoral labor supplies between the small open economy and a large country equalize:

$$N_{NT} = N^*_{NT}$$
$$N_H = N^*_F$$

Given that all shocks are constant in the steady-state, factor prices and shares of capital equalize in the H and NT sectors. Hence it must be true that:

$$MC_{NT} = MC_T = P_M$$

It is also true that:

$$M = (1-\upsilon_H)Y_H$$
$$VA = \upsilon_H Y_H$$

Sectoral markups in the steady-state equalize and are equal to:

$$mk_{NT} = \left[\frac{(\sigma_{NT} - 1)}{(\sigma_{NT} - 1)(1 - \tau_{NT})} \right]$$

$$mk_{H} = \left[\frac{(\sigma_{H} - 1)}{(\sigma_{H} - 1)(1 - \tau_{H})} \right] * \left(1 + \frac{\zeta * mk_{NT}}{\sigma_{H}} \right)$$

Then, it can be shown that:

$$R = R^{*} = \frac{P_{T}}{P_{NT}} = \frac{P^{*}_{T}}{P^{*}_{NT}} = mk_{NT} / mk_{H} + \zeta$$

and that:

$$T = T^{*} = \frac{P_{F}}{P_{H}} = \frac{P^{*}_{H}}{P^{*}_{F}} = 1$$

Now, using the definitions of price indices we can define the following price ratios:

$$\frac{P_{H}}{P_{T}} = \left((\lambda + (1-\lambda) \left(T \right)^{1-\phi} \right)^{\frac{1}{\phi - 1}} = 1 \qquad \frac{P_{F}}{P_{T}} = \left((\lambda T^{\phi - 1} + (1-\lambda) \right)^{\frac{1}{\phi - 1}} = 1$$

$$\frac{P_{H}}{P} = \frac{P_{F}}{P} = \frac{P_{T}}{P} = \left((\gamma + (1-\gamma) \left(R \right)^{\varepsilon - 1} \right)^{\frac{1}{\varepsilon - 1}} \qquad \frac{P_{NT}}{P} = \left((\gamma R^{1-\varepsilon} + (1-\gamma) \right)^{\frac{1}{\varepsilon - 1}}$$

For the large country, these price ratios are defined analogously.

The share of NT output relative to the H can be calculated using the demand functions and market clearing conditions:

$$\frac{Y_N}{Y_H}=\frac{\left((1-\gamma)\left(\frac{P_{NT}}{P}\right)^{-\varepsilon}+\zeta\gamma\left(\frac{P_T}{P}\right)^{-\varepsilon}\right)}{\left(\left((1-\omega)\gamma+\omega\gamma^*\right)\left(\frac{P_T}{P}\right)^{-\varepsilon}\right)}$$

Having established this relationship, it is easy to calculate the relative size of sectors.

ANNEX C.8. ELASTICITY OF DEMAND FACED BY EACH PRODUCER IN THE TRADABLE SECTOR

To ensure that the markups in the steady state equalize, the elasticity of demand faced by each producer in the tradable sector σ_H is set as follows.

Recall that in the steady-state sectoral markups are equal to:

$$mk_{NT}=\frac{\sigma_{NT}}{\sigma_{NT}-1}\frac{1}{1-\tau_{NT}}$$

$$mk_H=\frac{\sigma_H}{\sigma_H-1}\frac{1}{1-\tau_H}\left(1+\frac{\zeta(1-\tau_H)}{\sigma_H}mk_{NT}\right)$$

Now, since they are required to equalize (i.e., $mk_{NT}=mk_H$), the following problem needs to be solved for σ_H:

$$\frac{\sigma_{NT}}{\sigma_{NT}-1}\frac{1}{1-\tau_{NT}}=\frac{\sigma_H}{\sigma_H-1}\frac{1}{1-\tau_H}+\frac{\sigma_H}{\sigma_H-1}\frac{1}{1-\tau_H}\frac{\zeta(1-\tau_H)}{\sigma_H}\frac{\sigma_{NT}}{\sigma_{NT}-1}\frac{1}{1-\tau_{NT}}$$

Given that sectoral tax rates are the same, the above can be simplified to:

$$\frac{\sigma_{NT}}{\sigma_{NT}-1}=\frac{\sigma_H}{\sigma_H-1}+\zeta\frac{1}{\sigma_H-1}\frac{\sigma_{NT}}{\sigma_{NT}-1}$$

Which can be re-arranged to show that:

$$\sigma_H = \sigma_{NT}(\zeta + 1)$$

ANNEX C.9. CALIBRATED PARAMETER VALUES

Table C.1 Baseline Parameter Values

Description	Symbol	Value
Intertemporal discount factor	β	0.99
Coefficient of risk aversion	ρ	5
Frisch elasticity of labour supply	η	0.3
Elasticity of substitution between T and NT goods	ε	0.44
Elasticity of substitution between H and F goods	ϕ	2
Share of T goods in the consumption and investment	γ	0.4
Price elasticity of demand in the H sector	σ_H	9.6
Price elasticity of demand in the NT sector	σ_{NT}	6
Distribution margins	μ^D	37.5%
Distribution parameter	ζ	0.6
Steady-state revenue tax (in H and NT sectors)	τ	0.1
Mark-up	μ	1.33
Home bias	λ	0.7
Degree of openness	ω	0.3
Capital shares in the H and NT sectors	α	0.4
Steady-state capital depreciation rate	δ	0.025
Adjustment cost in changing capital stock	ν	3
Impact of quality changes on marginal cost of the firm	ι	0.1
Cost of undertaking positions in the international asset	NFA_P	0.007

Source: Author's compilation.