University of Glasgow

Barnaure, Vlad-Victor (2014) Essays on open-economy macroeconomics in emerging Europe. PhD thesis, University of Glasgow.

http://theses.gla.ac.uk/5036/

Copyright and moral rights for this thesis are retained by the author

A copy can be downloaded for personal non-commercial research or study, without prior permission or charge

This thesis cannot be reproduced or quoted extensively from without first obtaining permission in writing from the Author

The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the Author

When referring to this work, full bibliographic details including the author, title, awarding institution and date of the thesis must be given.

Glasgow Theses Service
http://theses.gla.ac.uk/
theses@gla.ac.uk

Essays on Open-Economy Macroeconomics in Emerging Europe

Vlad-Victor Barnaure

A thesis submitted in fulfillment of the requirements
for the degree of Doctor of Philosophy in Economics

Adam Smith Business School

College of Social Sciences

University of Glasgow

March, 2014

Abstract

Notwithstanding the proven achievements of the New-Keynesian research programme, the models currently used for monetary policy analysis rely on two assumptions that are often taken for granted. One is the balanced growth path property, which has generally been an accurate description of the US and other advanced economies. The other assumption concerns the small volatility of shocks that enables the researcher to approximate the solution of the original model locally. In the past decade, however, emerging economies such as China, Brazil, the Czech Republic or Poland have experienced persistent growth rates of GDP per capita that have been well above the corresponding levels in the euro area or the US. But how should monetary policy respond to an ongoing real convergence process which precisely differentiates emerging from advanced economies?

The first part of the thesis aims to answer this question in the context of economies also bound to become future members of the euro area. Owing to the long-term institutional commitment to satisfy the Maastricht convergence criteria during the ERM-II mechanism, policy makers in Central Europe face the additional responsibility of managing the tension between nominal and real convergence. For instance, the Balassa-Samuelson hypothesis postulates an empirically relevant reason as to why countries engaged in a catching-up process might experience a higher inflation rate brought about by the increase in the relative price of services. Motivated by the stylised facts of macroeconomic dynamics in the Czech Republic, a country we take as representative for the whole region, Chapter 1 develops a stylised SOE model with nominal rigidities that is subject to asymmetric productivity growth shocks affecting the traded and nontraded sectors. Relative to the existing literature analysing optimal monetary policy under commitment in Balassa-Samuelson type of macroeconomic environments, the model we propose differentiates itself in that it allows for endogenous current account fluctuations and uncorrected steady state distortions. These modifications result in richer dynamics, which are shaped by the possibility to influence the terms of trade in one's favour and the presence of monopoly power in product markets. In setting up the welfare maximising interest rate responses, the optimal plan trades off conflicting inflationary and deflationary incentives stemming from the existence of the above externalities.

Whereas the first chapter focuses on the methods and assumptions needed to detrend the nonstationary model, the second chapter examines the optimal monetary policy stance under real convergence in two different market structures. The simulations reveal that the specific policy recommendations depend on the degree of substitutability between domestic and foreign goods, a parameter which also alters the strength of the wealth effects driving consumption responses. When monopolistic competition in the traded sector is

assumed, the Ramsey interest rate plan is countercyclical. Owing to a cancellation of the terms of trade externality, the predictions are however reversed under perfect competition. This is because the incentive to stimulate production away from the inefficient steady state level becomes dominant. Additionally, the study conducts an extensive welfare analysis through which the effectiveness of inflation targeting and exchange rate peg regimes is assessed relative to the Ramsey plan. It is shown that policies achieving appropriate measures of price stability robustly deliver higher conditional welfare during a catching-up process. The analysis is suggestively complemented with policy experiments that are relevant to the ERM-II period, such as the Maastricht constrained optimal plan, its welfare costs and the welfare-maximising choice of a central parity at which the nominal exchange rate should be fixed.

The final part of the thesis examines the macroeconomic costs of euro adoption in Emerging Europe, conditional on the EMU membership eventuality. Inspired from the Optimum Currency Areas literature, the research conducted in the third chapter investigates the circumstances when the decisions made by the ECB would correspond to the domestic optimal interest rate responses. The empirical work looks at the structural alignment and the degree of business cycle synchronisation between prospective and current members of the single currency area, modelled suggestively as the Czech and Austrian economies. A rich SOE model with incomplete markets and trade in intermediate inputs is developed in this sense, whose core structure is similar to Kollmann (2001). Relative to the original framework, we augment its shock structure and enrich the dynamics by incorporating external habit formation and partial indexation in the Calvo adjustment rules for prices and wages. The state-space representation of the DSGE model is taken to data and the set of random parameters is estimated using Bayesian techniques. The comparative analysis reveals that most structural parameters are not very far from each other, suggesting that a moderate degree of structural convergence has been achieved by the emerging economy. The costs of losing monetary policy sovereignty are further assessed by employing a battery of tests, which include impulse response analyses and historical decompositions of output and inflation. While confirming previous SVAR evidence, the results suggest that the propagation mechanisms of monetary policy, productivity and demand shocks are remarkably similar across the two economies. In contrast, the analysis also indicates considerable asymmetries of the sources of fluctuations, which were more volatile and largely idiosyncratic in the Czech Republic. The low degree of business cycle synchronisation suggests that coping with euro area interest rates on a permanent basis is likely to be painful.

Contents

List of Tables

List of Figures

Acknowledgements

I owe my deepest gratitude to my parents, Mihaela and Horia, to my brother, Mircea, and to my girlfriend, Daria, for their patience, love and moral support. I thank my main supervisors, Professors Ronald MacDonald and Campbell Leith, for their guidance, research advice and excellent supervision throughout the past years. Above all, they have been inspiring mentors, who stimulated and challenged my thinking. I also thank Dr. Ioana Moldovan for her valuable comments and for accepting to become my secondary supervisor after the first year. I will always have a deep respect and gratitude for Prof. Altar Moisa and Prof. Andy Snell, for they have been the first professors who cultivated in me the passion for economics and finance. Without them and my supervisors, this journey would have been more difficult.

The research project has benefited from the comments and kind advice of many other people at various stages of writing. I am especially grateful to Dr. Konstantinos Angelopoulos, Dr. Xiaoshan Chen, Dr. Atanas Christev and Dr. Alberto Montagnoli for discussing my work at the SGPE annual PhD conferences and the Glasgow departmental seminars. They all brought appreciated contributions towards the development of the thesis in its early stages and helped improve its overall quality. I am equally grateful to Prof. Fabio Canova, Prof. Wouter den Haan and participants at the 2011 Barcelona Macroeconomics Summer School and the LSE Macroeconomics Summer Programme for introducing me to Dynare and to the Bayesian estimation of DSGE models. Their acknowledgement is important, as they taught me the technical background that was necessary to conduct my research. Special merits in this sense also go to the SGPE doctoral programme, which provided additional PhD classes in the first year.

Aleksandar Vasilev, Xuxin Mao, John Olukuru and Alex Kadow should not be omitted from this list. They have all been great colleagues, with whom I exchanged many interesting ideas, while also providing an intellectually stimulating research atmosphere.

Last, but not least, the support of the Economic and Social Research Council, who funded my doctoral studies, is gratefully acknowledged.

Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

The copyright of this thesis rests with the author. No quotation from it should be published in any format, including electronic and Internet, without the author's prior written consent. All information derived from this thesis should be acknowledged appropriately.

Signature

[redacted]

Printed Name: Vlad-Victor Barnaure
Date : March 17, 2014

Introduction

The fall of the Iron Curtain in 1989 marked the beginning of a new economic and political era for the former members of the Eastern Bloc. After four decades of isolation, the primordial objective of these countries has become to reestablish themselves as vibrant open economies, integrated in the European Union. The economic development that followed in the years to come has made the Central European region become known as Emerging Europe. The successful transformation of the Czech Republic, Hungary and Poland into the competitive open economies they are today has been the result of an assiduous process, characterised by the unexpected and, until then, unknown challenges of transition. This road from a centrally planned to a market economy was the first one of its kind. That is why it was often the case that the test was given to policy makers before the lessons were taught. Despite initial efforts to design and implement the most appropriate reforms, the first phase of the transition was marked by a prolonged recession (Blanchard, 1997). It was only when the role of institution building and the benefits of trade and financial integration were properly understood that the advantages of becoming a market economy could be fully enjoyed.

One major step towards creating an efficient institutional infrastructure was made when the preliminary EU accession negotiations were initiated. In turn, the prospect of joining the European Union - which materialised in 2004 - accelerated the pace at which reforms were adopted. In addition to the role played by the external EU conditionality in shaping up reforms in the institutional environment, new avenues for economic development were opened, as the region became increasingly integrated in the world economy. Central Europe emerged as an attractive destination for foreign direct investment. Owing to the benefits of foreign technological diffusion, such as the transfer of improved production methods, or the access to more advanced managerial and corporate governance systems, workers in Central European economies became more productive, their wages increased and therefore their standards of living improved. The amplitude of this real convergence phenomenon is presented in figure 1, where we show that all transition economies experienced an increase in GDP per capita relative to the corresponding levels in the euro area. Even though certain diversity exists among the new member states with respect to their initial levels of development and the speed of "catching-up" with the rest of Europe, the gap in the standards of living has narrowed significantly during the past decade.

Real convergence in Emerging Europe represents the fundamental theme of the present dissertation. The concept is revisited throughout the three core chapters, which focus on

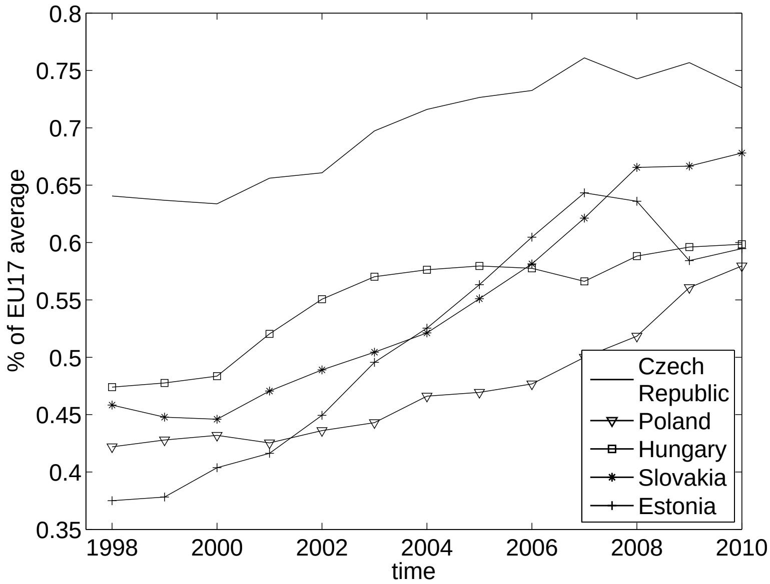


Figure 1: Per capita GDP in selected Emerging European countries, PPP standard

its implications for monetary policy and the prospects for euro adoption in Central Europe. The importance of monetary integration in the region should be well known to the reader. According to the TFEU[1], which is one of the core treaties defining how the EU operates, Central European economies have formal and temporary derogations from becoming full members of the European Monetary Union. As part of the process, they are required to participate in a constrained monetary policy arrangement - the exchange rate mechanism (ERM II) - and to meet a set of nominal convergence criteria for a two-year period. Through its assessment of four measures of nominal compatibility, commonly known as the Maastricht criteria[2], the ERM II mechanism has a gate keeping role in guaranteeing the efficiency of the common monetary policy in the EMU, which should not be disrupted by including additional members with different priorities. Even though Central European economies have certain room for flexibility in designing their euro adoption strategies, as they can choose both the timing of entering the exchange rate mechanism and the monetary policy regime in the intermediate period, the integration in the single currency

[1]The Treaty on the Functioning of the European Union (European Union, 2010).

[2]The specific measures of nominal compatibility refer to price stability, exchange rate stability, the convergence of long-term interest rates and a sustainable fiscal position. The specific meaning of these conditions is detailed in the Protocol on the Convergence Criteria annexed to the TFEU(2010), based on article 140: price stability is defined as a change in the CPI index that is lower than 1.5 percentage points over the average rate of inflation in the three countries with the lowest inflation rates; exchange rate stability is assessed, in principle, according to nominal exchange rate fluctuations within a 15% band relative to a central parity; the criterion on the convergence of interest rates means that a member state has had an average nominal long-term interest rate that does not exceed by more than two percentage points the average rate in the three best performing member states in terms of price stability; whereas fiscal sustainability translates into a budget deficit lower than 3% and a government debt level that does not exceed 60% of GDP - see Czech National Bank(2011) for further details.

area requires careful preparation and sound judgement in relation to the ongoing real convergence process.

There are at least two important dimensions through which real convergence affects the prospects for monetary integration and the worthiness of becoming part of the EMU.

On the one hand, when it refers strictly to improvements in the standards of living, the ongoing real convergence phenomenon increases the complexity of negotiating fit with the nominal entry conditions in the euro area. Part of the complications arise because periods of relatively high growth tend to be accompanied by an increase in the general price level (Begg et al., 2003; Lein et al., 2008). Owing to the inflationary effects envisaged by the Balassa-Samuelson effect (Balassa, 1964; Samuelson, 1964), meeting the price stability prerequisite for monetary integration might be a challenge.[3] The fact that price level convergence in Central Europe develops in parallel to and, to a certain extent, as a consequence of real convergence is not just a theoretical prediction. The empirical evidence provided by Lein et al. (2008) and Mihaljek and Klau (2008) using different methodologies suggests that Balassa-Samuelson type of inflationary effects are clearly present in the 1995-2008 period.[4] Moreover, the relevance of the Balassa-Samuelson inflation differential for the euro adoption decision is also acknowledged by central banks in their EMU accession strategies. For instance, the Czech National Bank (2007) notes that:

> "The higher degree of real convergence is fostering convergence of the price level, thus reducing the future pressures for equilibrium appreciation of the real exchange rate, which would result in an inflation differential against the euro area" (Czech National Bank)

Hence, managing the tension between nominal and real convergence is an important element in judging how monetary integration policies should be implemented in Central Europe. The conflict is not limited, however, to the possibility of being confronted with a higher inflation rate on the euro accesion path, that might pose a threat to the violation of the price stability requirement. The literature has been justifiably concerned about the potential incompatibility between the inflation and exchange rate stability criteria during the two year ERM II participation period, which should be traversed "without severe tensions" and "without devaluation on a country's own initiative".[5] Meeting the

[3] Other channels that might influence the relationship between nominal and real convergence are discussed in Lein et al. (2009) and include a higher elasticity of income of nontraded goods, credit growth or trade openness. Also, real convergence should bring about a decrease in macroeconomic volatility, which might alleviate inflationary pressures.

[4] Mihaljek and Klau (2004) and Égert et al. (2006) summarise the findings for the early transition period.

[5] Protocol on the Convergence Criteria of the TFEU(2010), article 3.

Maastricht target levels of the two variables can be problematic in the presence of perfectly mobile international capital flows (Begg, 2006), especially if not enough prior price level convergence is achieved. As the transition period to EMU can be regarded as a vast investment project, with significant returns accruing in the future, the expectations of nominal alignment and a stable exchange rate environment can create the premises for a surge in capital inflows. If this is indeed the case, a mix of exchange rate appreciation and higher inflation might be unavoidable. Moreover, stabilising two policy objectives at the same time can prove extremely difficult, as the Maastricht constrained policy makers have only the interest rate instrument available (Jonas, 2006).

On the other hand, the broader definition of real convergence which refers to the structural alignment and the business cycle synchronisation between Emerging Europe and EMU is highly relevant for quantifying the macroeconomic costs of monetary integration. According to the theory of Optimum Currency Areas, a low degree of business cycle synchronisation implies that coping with euro area interest rates on a permanent basis is likely to be painful. Hence, whereas the narrow concept of real convergence plays a critical role in assessing the challenges of entering euroland and raises many uncertainties concerning the optimal timing of the decision (Dyson, 2006), the broader concept of structural convergence underlines a longer-term view on the costs of losing monetary policy sovereignty.

Motivated by the nontrivial interdependence between real convergence and monetary integration in Emerging Europe, the research presented in the thesis addresses the following questions:

Q1. What is the optimal monetary policy stance under real convergence?

Q2. Is there a tension between the optimal plan and the Maastricht criteria? If so, how large are the welfare costs of the constrained optimal policy that meets the requirements of the ERM II mechanism?

Q3. What monetary policy strategy should be implemented during a period of high growth? Does the exchange rate regime affect the relationship between nominal and real convergence? Are inflation targeting regimes any better at maximising social welfare as compared to the fixed exchange rate alternatives? What is the appropriate level at which a central parity should be established during the ERM II period?

Q4. Are business cycles in Emerging Europe well synchronised with those in the euro area? Has enough structural convergence been achieved? Are these economies prepared for monetary integration?

In its quantitative investigation of the above research themes, the thesis develops two new models to study different aspects of monetary policy under real convergence (Q1-Q3), a topic that is the focus of Chapters 1 and 2, and to examine the degree of structural convergence between Emerging Europe and EMU (Q4), which is evaluated in Chapter 3. Since the set of potential structural representations of a complex real-world economy is very large and no model is fully accurate in the end, the frameworks we put forward are aimed only at highlighting the policy implications of some stylised macroeconomic developments in the Czech Republic. Despite the narrow focus on a single country, which is a consequence of the large number of structural parameters that have to be calibrated/estimated when working with DSGE models, the lessons that can be learned from our analysis should be generally applicable to all Emerging European economies.

The major themes outlined in Q1-Q4 are examined within the New Keynesian framework, an approach to business cycle analysis that has emerged as one of the most active and fruitful areas of research in modern macroeconomics. Whereas New Keynesian general equilibrium models vary in size, scope and complexity, their core structure combines the joint foundations of optimising behaviour by rational economic agents, that also appears in the RBC paradigm, with that of nominal rigidities and imperfect competition in the goods market. Owing to these features of the macroeconomic environment, the equilibrium allocation of the economy is influenced by the interest rate decisions made by central banks, thereby making monetary policy non-neutral in the short-run. Moreover, the underlying microfounded structure of these models provides a rigorous welfare metric - in the form of the utility of the representative household - through which normative policy questions such as the optimal conduct of monetary policy can be properly addressed. The last property is very useful for the analysis in Chapters 1 and 2, as these parts deal with concepts of optimality and a welfare-based evaluation of simple rules.

The two models presented in the thesis are developed in the tradition of Gali and Monacelli (2005), Clarida et al. (2001), Benigno and Thoenissen (2003), Benigno (2009), De Paoli (2009b), Kollmann (2001), Faia and Monacelli (2008), Masten (2008) and others, for they investigate aspects of monetary policy analysis and fluctuations within the small open economy paradigm. In these setups, decisions made by domestic agents do not have any influence on foreign variables. The small open economy paradigm is an accurate description of countries in Central Europe, which are very open (as their international trade to GDP ratio is over 100%) and relatively small (given their negligible weight in EU's GDP). Another shared feature of the two models is the assumption of incomplete markets, through which the current account plays a role in the transmission of macroeconomic shocks. Despite these similarities, the models are self contained and are used to examine different facets of monetary integration in Emerging Europe.

Chapter 1 opens the discussion with a set of stylised facts of macroeconomic fluctuations in the Czech Republic, which serve as a motivation for the subsequent analysis of monetary policy under real convergence. It is shown that the recent increase in GDP per capita relative to the euro area was driven by total factor productivity growth, which, in turn, affected the manufacturing and services sectors of the economy asymmetrically. Moreover, these developments in the real economy triggered an increase in the relative price of nontraded goods, indicating that the assumptions underlying the Balassa-Samuelson proposition should represent a reasonable description of the real convergence adjustment. Based on these premises, a small open economy model is derived from first principles to study the monetary policy implications of unbalanced growth between the traded and nontraded sectors. Relative to the extant literature analysing optimal monetary policy under commitment in Balassa-Samuelson macroeconomic environments, most notably the study by Masten (2008), the model we propose differentiates itself in that it allows for imperfect international risk sharing and uncorrected steady-state distortions.

Real convergence is modelled through a one-time, highly persistent innovation in manufacturing productivity growth. In turn, this convergence shock has a relatively large magnitude, for it triggers an initial increase in the aggregate growth rate of about 2 percentage points. The traded sector productivity gains, measured relative to both the nontraded sector and the foreign economy, continue to last for approximately 25 years. The analysis remains highly stylised and necessarily theoretical, however. This is mainly because the real convergence process is forward-looking. As a result, there are many uncertainties regarding its sustainability or magnitude. To overcome this issue, a set of alternative adjustments, which include different long-run relative productivity ratios and the case of full convergence, are considered in the sensitivity analysis.

Most debates in monetary economics have their roots in how monetary policy should respond to fluctuations around a balanced growth path. The objective of the modelling approach presented in the first chapter is however different. For instance, our analysis addresses the long-run policy implications of large deviations from the balanced growth path paradigm, that are associated with periods of persistent high growth. In the model presented in Chapter 1, the transition dynamics are exclusively driven by the convergence shock. The decision to switch off the stochastic elements in the economy is influenced by the nontrivial complications brought about by the presence of large nonstationary shocks and the assumption of incomplete markets. Owing to the history dependence of the equilibrium allocation, a nonstationary solution to the social planner's problem is not available and the use of perturbation methods becomes inappropriate. As a result, the study examines the convergence dynamics in a perfect foresight economy, where the future exogenous path of traded sector productivity is fully anticipated.

Particular to our investigation of optimal policy under real convergence is the application of a Ramsey type of analysis, where the planner maximises household's welfare conditional on the full set of nonlinear constraints implied by private sector's equilibrium conditions. Hence, the approach to deriving the optimal monetary stance in dynamic economies follows the tradition established by Ramsey (1927), Lucas et al. (1983) and applied more recently in New Keynesian contexts by Khan et al. (2003), Schmitt-Grohe and Uribe (2004) and Faia and Monacelli (2008). Given that agents operate in a perfect foresight world, the solution method used to determine the optimal transition paths is fully nonlinear.

The thesis then proceeds with a comprehensive analysis of the model's policy implications and a presentation of the results. Chapter 2 provides a detailed characterisation of the Ramsey plan and conducts an extensive comparison with the equilibrium allocations arising under a general class of simple rules. The latter encompasses an inflation targeting regime and a nominal peg as special cases. The transition dynamics are presented in relation to the Maastricht constrained optimal plan and the tension between nominal and real convergence conditional on the monetary policy regime in place is assessed.

The motivation for conducting these experiments is twofold. On the one hand, policy makers in Emerging Europe have implemented different monetary policy regimes during periods of high growth. For instance, the norm in the Baltic states has been to anticipate euro adoption by fixing the exchange rate against the single currency, whereas countries in Central Europe have opted for more flexibility by operating under inflation targeting regimes. To this end, the practical use of the analysis is that it sheds light on what monetary policy strategies are better suited - from a welfare point of view - during real convergence episodes. On the other hand, not much is known about what monetary policy strategy would be appropriate to follow during the ERM II transitory period. The successful euro adoption episodes of Slovakia and Estonia, which implemented inflation targeting and fixed exchange rate regimes for this purpose, do not provide sufficient historical insights in clarifying what options are better in negotiating fit with the Maastricht convergence criteria.[6] In this regard, the thesis seeks to clarify what specific constraints are expected to become binding during the ERM II period.

Lastly, motivated by the various nominal exchange rate trends that have been observed in Emerging European economies (presented in figure 2), the chapter considers the model's

[6] A study by Lewis (2009) provides an incipient attempt to answer this question, using a partial equilibrium model. By looking at various real convergence scenarios, the author concludes that an inflation targeting regime would offer better prospects of balancing the tension between the exchange rate and price stability criteria. The result is quite intuitive, as the flexibility in implementing monetary policy offered by a 15% percent fluctuation band around an appropriately chosen central parity is larger.

implications under both imperfect and perfect competition in the traded sector. The switch between these alternative market structures has nontrivial effects on the optimal policy problem, the trend adjustment of nominal exchange rates and the magnitude of the current account response implied by the model.

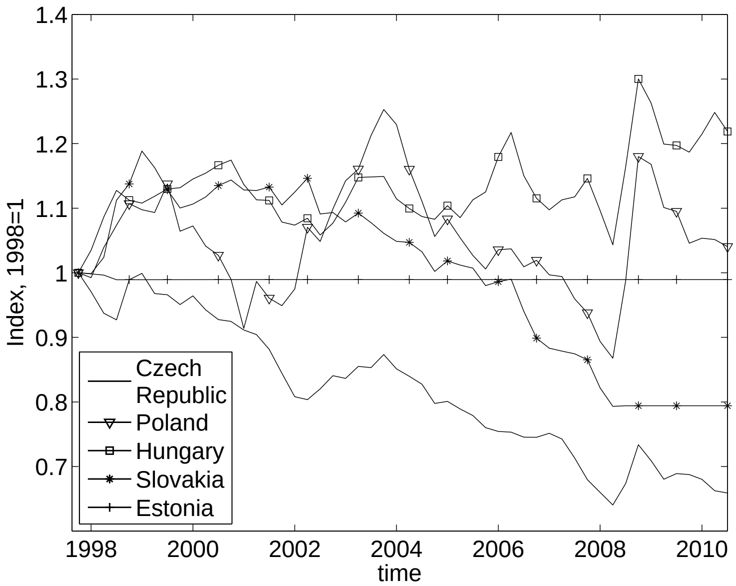


Figure 2: Nominal exchange rates against the euro

The contribution of the research presented in the first two chapters is that it provides a fresh perspective on how monetary policy should be conducted in the presence of incomplete markets and uncorrected steady-state distortions. In addition, the study promotes a unified treatment of optimal monetary policy in relation to various simple rules, thereby suggesting what regimes are better suited to implement under real convergence. All the recommendations made are based on an extensive welfare analysis, which sheds light on how costly it might be for a central bank to make inappropriate policy choices. Lastly, the study carries out new theoretical experiments that should be relevant to the ERM II period, such as a characterisation of the Maastricht constrained optimal plan under real convergence, its welfare costs and the welfare-maximising choice of a central parity.

In Chapter 3, the focus of the thesis moves towards understanding the nature of fluctuations in the Czech Republic in relation to those in the euro area. As prescribed by the theory of Optimum Currency Areas, an important factor which should be taken into account by an economy prior to integration within a monetary union is represented by its degree of business cycle synchronisation with the existing members of the union. Hence, the concept of structural convergence plays a critical role in assessing whether monetary integration is a sound long-run decision. For instance, if idiosyncratic features of the Czech economy are important, then coping with the policy decisions made by the ECB on a permanent basis might be painful. The transition from the "catch-up" to the "business cycle synchronisation" component of real convergence is accompanied by a change in the modelling approach that needs to be emphasised. The first part of the thesis focuses on deviations from the balanced growth path paradigm, in which the economy experiences periods of persistently high growth and the use of perturbation methods is problematic. By contrast, the second part of the thesis considers a structural analysis once the catch-up process has come to an end. In the alternative framework presented in Chapter 3, business cycles are isolated along a long-run, constant trend and local approximation methods become legitimate. A rich small open economy model with trade in intermediate inputs is developed in the spirit of Kollmann (2001) and Smets and Wouters (2003). Since the framework serves an empirical purpose, it incorporates a large set of nominal and real frictions, such as imperfect nominal adjustment with partial indexation in prices and wages, incomplete exchange rate pass-through, external habit formation and investment adjustment costs. All these structural features have been successfully incorporated in recent medium scale New Keynesian models for business cycle analysis. The model is estimated using Bayesian techniques and a structural comparison between the Czech and Austrian economies is made based on the set of estimated random parameters. It is shown that the model is capable of explaining important historical features of the data, suggesting that the DSGE framework we develop can become a reliable tool for policy analysis in Central European economies.

Two main results emerge. On the one hand, the analysis reveals that the propagation mechanisms of technology, monetary policy or demand shocks are remarkably similar across the two countries. On the other, the estimated filtered shocks and the historical decomposition of output and inflation indicate a strong incidence of asymmetric shocks in the Czech Republic. Owing to the last result, the empirical investigation makes the case for monetary integration particularly weak.

Chapter 1

Unbalanced Growth in a Small Open Economy Model

> "The likely continuing presence of a Balassa-Samuelson effect is a seriously complicating factor in the path of integration of the transition countries into the ERM-II and the Euro area"
>
> Begg et al. (2003)

> "Allowing for sectoral asymmetries is (...) especially important in analysing monetary policy for an open economy "
>
> Woodford (2003)

The unique aspects of the real convergence model of Emerging Europe, which pertain to both the transition experience and the European integration process, have attracted widespread attention in policy circles. For instance, the recent book by Martin and Winkler (2009) includes a comprehensive collection of papers presented at the second ECB conference on Central and Eastern Europe in 2007, all of which examined different facets of the real convergence phenomenon. The ideas disseminated in these contributions refer to the determinants of growth in the region, the sustainability of the convergence model or the potential tension between nominal and real convergence in relation to the monetary integration process.

Nonetheless, the very important topic of how monetary policy should optimally respond to long-term adjustments in the standards of living has remained largely unexplored. Exceptions are the models by Ravenna and Natalucci (2008) and Masten (2008) that will be discussed later on in this chapter. An examination of the optimal interest rate response under real convergence is not only relevant to policy makers in emerging markets, but should also become a focal point on the research agenda in monetary economics. Part of the motivation in this sense is provided by the findings of Aguiar and Gopinath (2007), whose estimation exercise has shown that shocks to trend growth are the primary source of fluctuations in emerging economies. Without an adequate acknowledgement of the role played by permanent shocks, business cycle models cannot be reconciled with the some defining characteristics of these countries, such as the high consumption-output volatility ratio.

Up to now, research analysing policy issues in emerging economies mainly addressed particular structural features of the macroeconomic environment. Cespedes et al. (2004) examined the topics of liability dollarisation and the balance sheet effects of exchange rate depreciations; credit market frictions and external financing constraints were addressed by Devereux et al. (2006); Gertler et al. (2007) and Elekdağ and Tchakarov (2007), whereas Batini et al. (2009) introduced a commodity sector to illustrate the dependence of some emerging economies on revenues from natural resources. Furthermore, partial dollarisation in a dual currency environment was studied by Castillo et al. (2006), and, more recently, Seoane (2010) examined the evidence on regime switching in an estimated DSGE model of Mexico. Yet, an important distinguishing feature of emerging markets, namely that these economies tend to experience episodes of high growth and real convergence, remained mostly overlooked in the current vintage of New Keynesian models. For instance, Galı et al. (2003) derived the optimal monetary policy response with respect to technology shocks, with productivity growth being modelled as an AR(1) process, and used the insights provided by the basic New Keynesian model to evaluate Fed's macroeconomic performance in the Volcker-Greenspan era. Their closed economy results have been further extended recently by Mattesini and Nisticò (2010), who augmented the previous specification with a drift component, thereby allowing for trend-growth. In the two-sector open economy model of Liu and Pappa (2008), which focuses on the gains from international monetary policy cooperation, productivity growth is simply modelled as a random walk. A defining characteristic of all these studies is that shocks driving trend productivity away from the balanced growth path are small. Because persistent and potentially large deviations from the balanced growth path paradigm have become more discernible in the new economy, being observed in the East Asian and Central European parts of the world, their relevance to current economic debates cannot be denied.

A primary objective of the first part of the thesis is to bridge the gap in the literature on monetary policy in emerging market economies. In addition to deriving the optimal policy response during periods of high growth, which is the main theme of the analysis, the scope for understanding the effects of real convergence on an economy is vast. Even though this phenomenon has been an empirical fact in recent years, many normative policy questions have remained largely unaddressed. Are current account deficits desirable during periods of high growth? What types of trends in relative prices should be expected? Is there a scope for consumption booms? Providing rigorous answers to many of these questions requires the development of a macroeconomic framework in which they can be properly addressed. Chapters 1 and 2 respond to this increasing need by proposing a new dynamic general equilibrium model for policy analysis in nonstationary environments. In light of the fact that emerging European economies are bound to become future members of the euro area, this framework is also explored to gain additional insights. Specifically, it is used to analyse the potential challenges that policy makers in the region might face during EMU accession. On the one hand, the model seeks to clarify which of the Maastricht constraints are most likely to be binding during the ERM II period, conditional on the monetary regime in place. On the other hand, our analysis is also aimed at quantifying the welfare costs of complying with the convergence criteria under the constrained optimal plan.

Conventional economic thought (e.g. Baumöl, 1967) states that countries engaged in a catching-up process tend to experience unbalanced growth patterns in manufacturing and services, with the productivity gains in the former sector being larger.[1] This stylised fact equally applies to the macroeconomic developments in the Czech Republic over the past fifteen years.[2] The evidence in figure 1.1 reveals that real convergence has been accompanied by higher traded sector productivity gains in the labour market, which brought about a relative increase in nontraded goods inflation. These features of the data indicate that the assumptions underlying the Balassa-Samuelson proposition should represent a reasonable description of the real convergence adjustment. Altogether, the persistent period of higher real GDP growth relative to the euro area contributed to a closer alignment in the standards of living. In this respect, panel (c) shows that the PPP adjusted relative real GDP per capita smoothly increased from 64% to 76% over the 2000-2007 period.

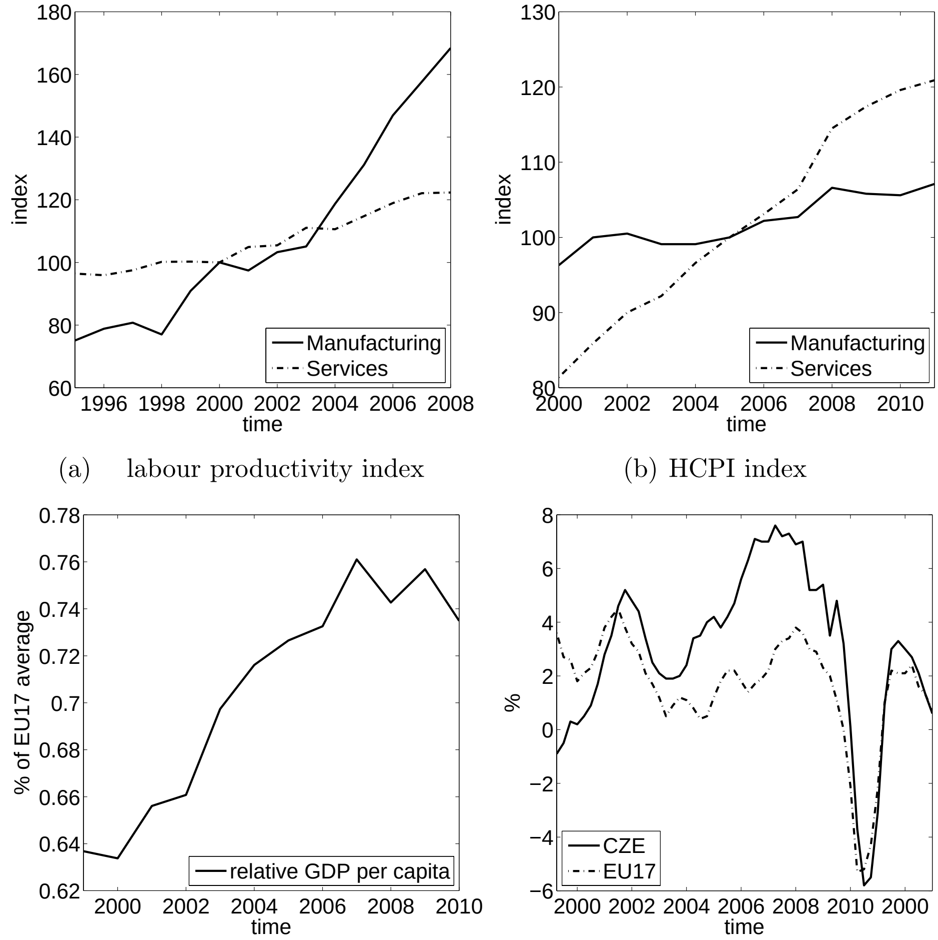
The model we develop in this chapter takes into account the above evidence and has the unbalanced growth patterns embodied in its two-sector, open economy structure. The following section motivates even further some of assumptions underlying our model, for it provides important insights about the drivers of growth in the Czech Republic.

Determinants of Real Convergence in the Czech Republic

There is a general consensus in the literature about the unique aspects of the real convergence process in Central Europe. In contrast to Asian emerging economies, where growth has been explained by the neoclassical capital accumulation channel, the increase in income per capita in the region has been driven by total factor productivity (Bini Smaghi, 2007). Two recent growth accounting exercises by Arratibel et al. (2007) and Borys et al. (2009) provide robust empirical evidence to support the above hypothesis.

[1]Throughout the thesis, the terms manufacturing - traded ; services - nontraded will be used interchangeably.

[2]In terms of its parameterisation, the model is aimed at roughly reflecting the Czech real convergence experience. However, the country is generically taken as representative for the whole Central European region.



(a) labour productivity index

(b) HCPI index

(c) GDP per capita, PPP standard

(d) Real GDP growth

Figure 1.1: Czech Republic - real convergence indicators[3]

[10] Data sources: (a) OECD - STAN database, (b),(c),(d) Eurostat

Due to its individuality among other emerging markets, the real convergence model of Central European economies has provoked the curiosity of academics for understanding the foundations of growth in the region.[4] Why is technology, and not capital accumulation, the main factor responsible for the catch-up phenomenon? A sensible answer to this difficult question cannot be given without placing the developments of the past two decades in a historical context.

The remarkable growth performance of the Czech Republic has been contemporaneous with the last stages of the transition to a market economy and the European integration process. Both factors shaping domestic transformation were political by nature, as they critically depended on the policy makers' views about the speed and types of reforms

[4] A conference dedicated to the topic was organised by the European Central Bank in 2007; see Martin and Winkler (2009).

that had to be adopted. Two important reform classes can be distinguished according to Svejnar (2002), who studies the success of the institutional and economic transition process in the 1990's. On the one hand, Type I reforms were associated with decisions aimed at reducing the role played by the state in the economy. These involved macroeconomic stabilisation, microeconomic restructuring, including the privatisation of inefficient state owned enterprises, or the elimination of subsidies and price controls. On the other hand, the aim of the second class of reforms (Type II) was to develop institutions and regulations that would enable the successful functioning of a market-oriented economy. By enforcing the rule of law and guaranteeing the protection of property rights, these reforms stimulated the creation of a business friendly regulatory environment.[5] While the Czech Republic made considerable progress in the 1990's in implementing Type I reforms, the development of effective institutions lagged behind (Svejnar, 2002). The most important lesson to be learned from the early transition period is that neither the transferal of governance to private managers and ownership to private investors, nor the creation of new firms, are sufficient by themselves for creating the premises for sustainable growth, if they are not supported by well functioning institutions. Noteworthy examples in this sense are the failure to advocate good corporate governance and managerial systems after the mass privatisation programme[6], or the poor performance of the banking system (see Cull et al., 2002), which maintained soft budget constraints in place.[7] The lack of effective market-oriented mechanisms that would discipline troubled companies in pursuing deeper reforms and restructuring, and sanction incompetent managers for their deficient performance, while maintaining in place constraints on limiting productivity enhancements, indicates that the scope for efficiency gains in both the public and the private sector was still large. It is therefore not surprising that Czech output was still below the pre-transition level in 1997-1998, as the country experienced a severe recession and a banking crisis.

During the same period, the preliminary EU enlargement negotiations were initiated. The process constituted an essential catalyst in promoting and enforcing sound institutional and economic practices that were common in the single market. As we shall argue below, both the institutional reform and the benefits arising from more economic integration with technologically advanced trading partners contributed to the increase in total factor productivity.

[5] Pistor et al. (2000) offer an extensive discussion on law reform in transition economies and its effects on corporate governance and external financing.

[6] The widespread use of expropriation techniques at the expense of minority shareholders and creditors in the Czech Republic led to the introduction of a specific term for such behaviour - tunneling - see Johnson et al. (2000).

[7] See Djankov and Murrell (2002, p.771-772). The study extensively surveys the research on enterprise restructuring in transition economies.

In order to become a member of the European Union, the Czech Republic was required to adopt a whole set of legislative norms and to make its market economy compatible with the *Acquis Communautaire*. One advantage of accommodating the EU legislation was that it served as an external anchor in shaping and monitoring domestic transformation even in areas where vested interest groups would have hindered the reform process. Examples in this direction include the elimination of state subsidies as a way of socialising the costs of economic inefficiency or the exposure to increased foreign competition, as the economy became more open and trade barriers had to be removed for participating in the single market. Hence, by ensuring that domestic agents operated in increasingly competitive and less regulated markets, the external enforcement of the acquis was able to change the return structure of carrying the needed institutional and governance reforms. Inefficient firms would have had their survival threatened under the new set of rules.

As North (1990) observes, "the incentives that are built into the institutional framework play the decisive role in shaping the kinds of skills and knowledge that pay off." From this point of view, it can be suggested that by opening the road to more integration in the product and financial markets, while ensuring a better protection of property rights and a more transparent legislative framework, the balance between acquiring skills that result in income redistribution (such as the expropriation of minority shareholders or taxpayers) at the expense of pursuing productivity enhancing activities has shifted in the favour of the latter. Hence, institutional reform changed the incentives and scope for achieving productivity gains.

A second important aspect of adhering to EU legislation was that it guaranteed the stability and predictability of the future institutional architecture. A positive effect of this expected convergence path in institutions was that foreign investors became particularly interested in relocating their capital in the Czech Republic. As Lipsey (2006) observes, "countries that provide reliable and predictable legal systems and efficient public administration may receive more investment and profit more from it than countries with poor governance". In the context of the European integration process, several factors can be put forward to explain the surge in foreign direct investment, whose stock as percentage of GDP evolved from 12.6% in 1995, to 48.1% in 2005. On the one hand, the prevalence of the acquis over national legal standards meant that part of the sunk costs (legal expertise, knowledge of country specific norms, monitoring costs) and risks (law enforcement, unexpected changes in legislation) associated with expanding in the Czech market disappeared. On the other hand, foreign investors benefited from the low costs of production and the increasing openness of the economy, all of which established the premises for growth in both the domestic and export markets. Moreover, an essential determinant of the investment decision was the high absorptive capacity of the Czech economy, which had a pool of skilled labour force capable to apprehend, use and implement new technologies (see Arratibel et al., 2007; Dyson, 2006). In line with the findings in Borensztein et al. (1998), the quality of the human capital has defined a stronger link between technology diffusion from foreign firms and growth.

There are several channels through which foreign direct investment might have a positive effect on the domestic economy. First, FDI augments the capital stock and can accelerate the convergence of an economy to its steady state along the lines of the neoclassical growth model.[8] Second, foreign direct investment tends to be carried out by technologically advanced firms such as multinational enterprises, whose knowledge of international markets, better corporate governance, marketing and risk management techniques or improved production methods can reduce the inefficiencies in the acquired company and lead to productivity gains. As we mentioned before, much of the success of the above diffusion process depends on the absorptive capacity of the targeted firm. Third, the positive effects arising from technological transfer may spill over to firms in the same industry (horizontal diffusion) or via forward and backward production linkages (vertical diffusion). Whereas most empirical studies tend to agree that foreign participation increases the productivity of the domestic affiliate, confirming the second channel, less, more complex and potentially contradictory evidence is found for spillover effects that might benefit local firms. Such gains may arise from the imitation of the more advanced production methods or by hiring former employees of the foreign competitors. Since a summary of the extensive literature analysing the relationship between FDI and growth is beyond the scope of our study, we refer the reader to the recent summary of the empirical literature by Lipsey (2006), which focuses on Central Europe.

What becomes clear from our analysis is that the role played by total factor productivity in driving growth should not be perceived as surprising. The specific historical influence of the transition experience and the European integration process facilitated the development of better institutions, more openness of the goods and financial markets and an access to improved production methods via foreign technological diffusion. While the EU membership conditionality shaped the institutional reform and, by reducing the costs on society, contributed indirectly to a better economic performance by firms, the adoption of foreign technology and foreign managerial and corporate governance systems was the key factor explaining the large gains in total factor productivity documented before.

In light of these considerations, the key channel through which real convergence operates in our model will be represented by technological progress in the traded sector.

[8] To the extent that cross border flows represent greenfield investment and not acquisitions.

1.1 Related Literature and Contribution

The theoretical framework we propose belongs to a novel literature that aims to assess the importance of productivity growth on the design of macroeconomic policy in Emerging Europe. Much of the development in the field is inspired from the original Balassa-Samuelson hypothesis, although the optimal policy and monetary integration implications of real convergence are examined within dynamic general equilbrium models.[9] Moreover, the studies to be reviewed in this section have a common denominator. They evaluate whether real convergence poses a threat to the fulfillment of the long-term institutional arrangements that countries in Central Europe are bound to. As it is well known, the most influential ideas currently guiding monetary policy in the region are about when to adhere to the Exchange Rate Mechanism II and whether the prospective adoption of the single currency would be attainable under real convergence.

Managing the tension between nominal and real convergence is an important element in judging how monetary integration policies should be implemented in Central Europe. The challenges towards entering euroland mainly refer to the inflationary effects that periods of high growth can bring, as predicted by the Balassa-Samuelson effect. As a result, the price stability criterion required for EMU accession might be violated. A second potential difficulty that central banks are faced with during the ERM II adjustment is that they will have to meet two different - exchange rate and inflation - stabilisation objectives while having only the interest rate instrument available. To this end, it is important to investigate which of the Maastricht constraints are expected to be binding and to check whether the above property applies to more than one convergence criteria. Lastly, even if a Maastricht compliant monetary policy response can be engineered, the constrained adjustment might still result in substantial welfare losses. Thus, monetary integration involves tradeoffs between implementing monetary policy optimally under real convergence, on the one hand, and satisfying the Maastricht constraints on the other.

Ravenna and Natalucci (2008) are the first authors to examine the optimal conduct of monetary policy under unbalanced growth in a two-sector open economy environment. Their study focuses on simple instrument rules and compares the welfare properties of fixed exchange rate and inflation targeting regimes. Ravenna and Natalucci show that policies aimed at stabilising the nominal exchange rate are suboptimal, for they augment the welfare loss by an order of magnitude relative to the best performing simple rule. Another important insight this study brings is that the monetary policy regime

[9] An early examination of the Balassa-Samuelson effect in a two-country, RBC model is carried out by Asea and Mendoza (1994).

in place influences the equilibrium allocation of nominal (but not real) variables in a Balassa-Samuelson dynamic model. Additionally, the authors also address the potential incompatibility between real convergence and the prospect of joining a monetary union. In this regard, the conclusions put forward by Ravenna and Natalucci suggest that the phenomenon of real exchange rate appreciation severely restricts the class of simple rules that maintain inflation and the exchange rate within the Maastricht numerical boundaries.

Even though the above study brings many conceptual insights and is meritorious for opening a new strand of literature, it has a clear methodological drawback, as indicated by Masten (2008). Ravenna and Natalucci derive the conditional dynamics of the economy under the two regimes by adopting a local approximation to the true solution around the nonstochastic steady state. However, the solution method circumvents the well known fact that perturbation techniques are no longer appropriate when the size of the shocks hitting the economy is large. This is indeed the case when a real convergence phenomenon is at work. Instead, the correct methodology should have in mind the treatment of nonstationary productivity trends and a model-based detrending procedure through which an alternative stationary representation of the dynamic system can be achieved. By investigating the latter, the researcher can then study the effects of temporary shifts in productivity growth on the endogenous variables. This approach contrasts the experiment conducted by Ravenna and Natalucci (2008), who examine the effects of large, transitory shifts in the traded sector productivity level. In light of the above limitations, the results put forward by Ravenna and Natalucci (2008) should be interpreted with care. For instance, the real exchange rate appreciation is only a temporary - but not a trend - phenomenon.

The above methodological problems have been addressed by Masten (2008), whose study examines optimal commitment policy under real convergence. In order to allow for an appropriate detrending procedure, Masten's stochastic model has a simplified production structure, that uses labour as the single input.[10] In contrast to Ravenna and Natalucci (2008) who discuss simple rules, Masten (2008) characterises optimal policy under commitment using a linear-quadratic approach. The author finds in his baseline model, distinguished by a depreciating nominal exchange rate trend, that optimal policy is countercyclical and triggers moderate increases in both nominal and real interest rates. The optimal response of the instrument variable results in a mix of inflation and deflation in the nontraded and traded sectors respectively, which causes aggregate inflation to only slightly deviate from steady state along the transition path. As the real convergence phenomenon brings about only moderate inflationary pressures, Masten (2008) concludes

[10] Two other departures from the previous contribution are related to the presence of complete asset markets and the possibility of price setting in the traded sector.

that the prospective catch-up should not be an impedient to EMU accession.

In spite of moving the literature in the right direction, Masten (2008) only partially addresses the design of a theoretically consistent detrending procedure. On the one hand, a clear methodological flaw is that Masten works with rescaled price indexes, which are by no means stationary variables.[11] Even though this observation is obvious if we consider an economy that has a steady state inflation of 2% per year, the author incorrectly argues that his rescaling procedure for prices is valid. As we shall see throughout this chapter, a better approach is to express the equilibrium conditions in terms of inflation rates and relative prices before any normalisation to the nonstationary model is carried out. On the other hand, given that Masten's exposition of the dynamic system is in transformed form, the author does not discuss whether a mapping between the nonstationary and scaled forms of the decentralised allocation exists. In particular, the CES specification of the consumption aggregates has to impose either unitary or infinite values to the elasticity of substitution between domestic and foreign goods for the rescaling procedure to work.[12] Whereas the baseline calibration in Masten (2008, p.131) is consistent with the appropriate restrictions, the author also discusses an alternative parameterisation of his model where the stationarity inducing transformations would not be possible. By addressing the above problems, the methodology presented in this work represents an improvement relative to the approaches currently available in the literature.

Masten's results are contingent on the common but highly restrictive assumption of perfect risk pooling of output fluctuations at the international level. The complete asset markets structure has been heavily criticised for two reasons. One line of research focuses on the restrictions imposed on the real exchange rate dynamics. As Chari et al. (2002) demonstrate, a postulate of the complete asset markets paradigm is that real exchange rate dynamics are perfectly correlated with the ratio of marginal utilities of consumption. Empirical studies, however, often find negative cross correlations between the two variables (Kollmann, 1995; Ravn, 2001), a contradiction that has been labelled, *inter alia*, the consumption-real exchange rate anomaly (Benigno and Thoenissen, 2008) or the Backus Smith puzzle (Corsetti et al., 2008b). A second unlikely prescription of perfect risk sharing is that, under the standard assumptions of power utility, Cobb-Douglas aggregates of domestic and foreign goods and a zero initial net foreign assets position, the current account becomes unresponsive to macroeconomic shocks.[13] Since all the above assumptions are an integral part of Masten's analysis, the predictions generated by his complete

[11]See Masten (2008, p. 123, footnote 4).

[12]A formal proof is presented in Appendix C.

[13]See Ghironi (2006, p.429) for a discussion. Even if the elasticity of substitution is not restricted to one, the current account is determined residually and plays no role in influencing the transmission of shocks.

markets model are largely at odds with the persistent current account deficits observed in emerging European economies. The scale of this phenomenon has been emphasised by Obstfeld and Rogoff (2009) in a recent paper, who noted that Central and Eastern European economies were ranked second in the world in terms of their current account deficit record. As the historical evidence presented in figure 1.2 suggests, the design of a macroeconomic framework which studies the implications of real convergence in Emerging Europe should not ignore the potential that foreign capital has in serving as a vehicle for intertemporal consumption smoothing. If a theoretical model implies that current account deficits are optimal during periods of high growth, then the use of perturbation methods is still inappropriate. The reason why this is the case is similar to the one prescribed by the permanent income hypothesis. Even though nonstationary trends are removed by rescaling the decentralised allocation, detrended consumption might still significantly jump in response to the permanent shock. One important contribution this thesis makes in this sense is to examine two alternative instances where consumption jumps may or may not be implied by an imperfect risk sharing model.

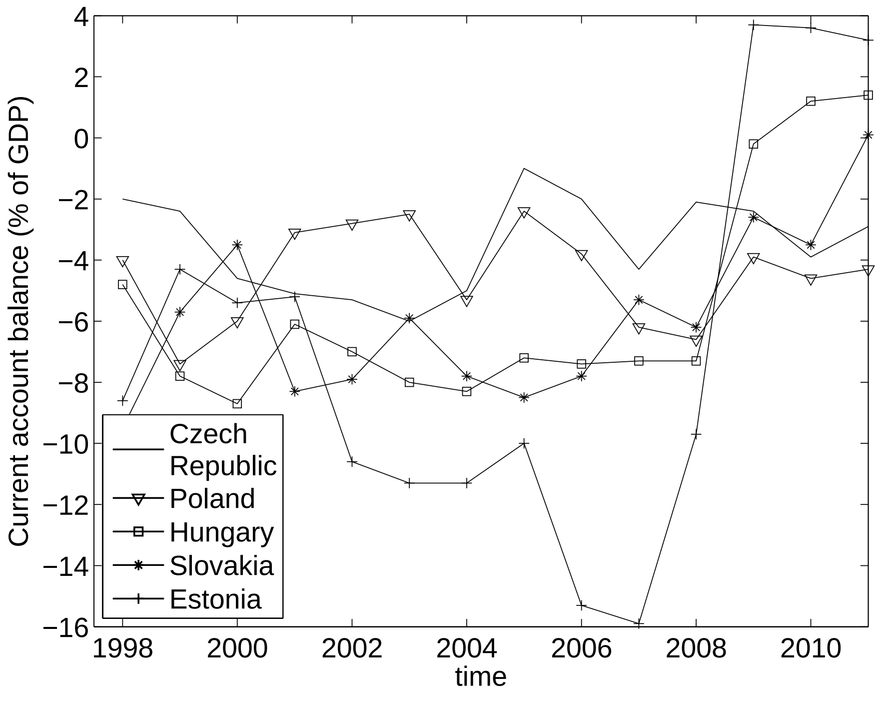


Figure 1.2: Current account balance - historical evidence

Lipinska (2008) adds a new flavour to the discussion, by asking how the Maastricht constrained optimal policy is different from the standard case. Derived within a linear quadratic framework, her results show that the convergence criteria augment by 30% the initial deadweight loss associated with the optimal monetary policy. She also finds that the Maastricht-constrained optimal plan leads to a smaller variability of aggregate inflation, the nominal interest rate and the nominal exchange rate. Even though this research avenue is both promising and relevant to policy makers, we feel that analysing the Maastricht constraints without relating to the real convergence phenomenon is only an incipient step towards a more realistic analysis. The constrained dynamic system is also investigated by Jenish (2008), who reports that a mix of fiscal and monetary policies is needed to guarantee its stability. The novelty, in this case, lies in introducing a fiscal dimension to the Maastricht convergence criteria and the policy design problem.

This study contributes to the current state of research in many ways. First, it examines how monetary policy should be conducted in a small open economy under imperfect risk sharing and uncorrected steady state distortions in the goods market. By considering the above extensions to the Masten economy, our model brings fresh insights not only on how the above externalities influence the Ramsey allocation and the optimal interest rate response, but also on the correct methodology needed to study the monetary policy implications of unbalanced growth. It is shown that, in the class of models with perfect labour mobility considered in the literature, only two values of the traded elasticity of substitution - unitary or infinite - are consistent with the existence of a detrending procedure that renders the model stationary. In light of this finding, the Ramsey plan is discussed under two alternative market structures represented by monopolistic and perfect competition in the traded sector. This novel comparative perspective is important, as altering the value of the trade elasticity of substitution is highly consequential for the optimal monetary policy stance under real convergence, the trend evolution of relative prices and the magnitude of the current account dynamics implied by the model.

Second, the research provides a unified treatment of the Ramsey plan and the equilibrium allocation arising under a general class of optimised simple rules. The assessment of what monetary policy strategies perform well under real convergence and in alternative market structures is based on an extensive welfare analysis, which is novel and adds value to previous studies that have a more limited focus. Ravenna and Natalucci (2008) study only the effects of simple rules, whereas Masten (2008) examines only the optimal commitment policy.

Third, the present work conducts several theoretical experiments that have not been carried out before. For instance, we analyse the welfare maximising choice of a central parity during the ERM II period. Moreover and in the spirit of Lipinska (2008), we also examine the equilibrium and welfare properties of the Maastricht constrained optimal plan.

A final distinctive feature is that a fully nonlinear solution method is used for determining the equilibrium allocation, under the assumption of perfect foresight. The above approach is mainly intended to preserve the consistency of the solution methods used throughout the analysis. To understand why the attention is restricted to the class of deterministic models, it is important that some technical considerations are emphasised.

A critical difficulty that prevents us from generalising all our results to a stochastic economy lies in the dependence of the equilibrium allocation on the level of the net foreign assets position. As a result, a nonstationary solution to the social planner's problem is not generally available and the sticky price allocation cannot be expressed in terms of deviations from that efficient allocation.[14] The fact that a measure of efficiency cannot be analytically derived does not pose any problem if one investigates a stationary model and then approximates its solution around a deterministic steady state.[15] In our case, however, the convergence shock refers to a nonstationary movement in traded sector productivity that has a large magnitude. Given that consumption jumps and persistenty large current account responses are implied by the model when perfect competition in the traded sector is assumed, there are no adequate tools that can allow us to study the effects of uncertainty in addition to the real convergence adjustment. For instance, determining the equilibrium allocation in a stochastic environment requires the use of projection methods, whose computational implementation is likely to become unmanageable. A similar concern applies to the computation of the Maastricht constrained optimal plan, which is a nontrivial problem by itself even when the economy is deterministic.

Our findings suggest that: (i) the optimal monetary policy stance under real convergence depends on the degree of substitutability between domestic and foreign goods and the market structure in the open sector; (ii) inflation targeting regimes perform best; (iii) the relationship between nominal and real convergence depends not only on the structural features of the model, but also on the monetary policy regime in place; (iv) the welfare maximising choice of a central parity is consistent with moderate levels of trend implied variation of the nominal exchange rate; (v) the welfare costs of complying with the Maastricht constraints under real convergence are relatively low.

[14]An exception is the baseline case of a unitary elasticity of substitution, where movements in the terms of trade ensure perfect risk sharing and the financial structure of the model is largely irrelevant (Cole and Obstfeld, 1991; Corsetti et al., 2008b). In that instance, the Pareto optimal allocation is analytically available as Masten (2008) shows. This is the only special case when our results can be extended to a stochastic economy.

[15]See Kollmann (2001) for an example.

1.2 The Model

We formulate a small open economy model that is subject to unbalanced growth across the traded and nontraded sectors. In the context of this framework, we study the implications of real convergence for optimal monetary policy, EMU integration and the welfare performance of simple rules.

The structural features of the model are explained in detail for the case of monopolistic competition in the traded sector, where preferences over domestic and foreign goods have a Cobb-Douglas functional form.[16] We then show that only two values of the trade elasticity of substitution are consistent with the existence of a detrending procedure. This chapter is closed with the derivation of the Ramsey plan, whose implications for the optimal conduct of monetary policy are examined in Chapter 2.

1.2.1 Overview and Description of the Building Blocks

The home emerging country is populated by a representative household who consumes goods belonging to the tradable and nontradable sectors. Since the economy is open to international trade, part of the tradable consumption is supplied by the foreign economy and part of the domestic tradable output is exported. Domestically produced traded goods are indexed by H, goods produced abroad are indexed by F, while the nontraded domestic output is indexed by N. In both sectors, there is a continuum of intermediate goods producers, who operate in a monopolistically competitive environment and are are subject to nominal rigidities in their price setting decisions. The only input used in production is labour, which is hired in competitive markets. Notice that the model abstracts from capital accumulation, which may be an important catalyst for real convergence. However, the empirical evidence in Arratibel et al. (2007) and Borys et al. (2009) suggests that the capital accumulation channel did not have a major influence in triggering high growth over the past decade. As the real convergence of emerging European economies was mostly explained by total factor productivity shocks, we believe that focusing on this particular stylised fact is important. The choice is also motivated on analytical grounds, because we want to derive the policy implications of our experiments while keeping the framework as simple as possible. A distinguishing feature of the economy refers to the presence of nonstationary productivity shocks in the traded sector, that allows for a proper simulation of the Balassa-Samuelson effect. The last assumption imposes considerable

[16]The alternative adjustment arising when perfect competition in the traded sector is assumed is considered later on in Chapter 2.

restrictions on the class of admissible preferences that allow a long-run balanced growth path property (Ireland, 2004b; King et al., 1988). Throughout the model, the distinction between nonstationary and detrended variables is made using capital and small letters.

The goods produced by individual intermediate firms, indexed by h and n and supplied in many varieties, are further aggregated by competitive final goods producers. While the law of one price holds for internationally traded goods, two sources of deviation from purchasing power parity are allowed for in the model, namely home bias in consumption and the existence of nontraded goods.

Asset markets operate under perfect risk sharing at the domestic level, as consumers are assumed to have the same initial level of wealth. This assumption is necessary to maintain the representative agent paradigm. On the other hand, risk pooling of output fluctuations is incomplete at the international level. In this regard, domestic agents have access to a foreign bond, whose gross rate of return follows an exogenous process. The presence of incomplete asset markets requires an adjustment mechanism to deal with the indeterminacy of the net foreign assets position which arises in these setups, a problem that has been discussed in various places in the literature (Driver et al., 2005; Ghironi, 2006; Schmitt-Grohé and Uribe, 2003). The stationarity is ensured here by introducing a risk premium on the external position whenever the latter deviates from its steady state level. In this way, a productivity shock does not have permanent wealth effects by altering the optimal holding of the international bond.

1.2.2 Inducing Stationarity in DSGE Models with Nominal Variables

The study of economic growth, business cycles and their interaction has been been the modus operandi of the RBC research programme (see Cooley and Prescott, 1995). From this perspective, economic fluctuations are traditionally insulated by detrending the neoclassical framework along a balanced growth path, which is compatible with the stylised long-run dynamics of macroeconomic variables for developed economies. Even though the above methodology is attractive from a conceptual point of view, the simultaneous study of growth and fluctuations imposes certain restrictions on the functional forms admissible within the optimisation problems faced by agents. While the production side requirements are commonly known from the Solow-Swan model, entailing a labour augmented technological process, King et al. (1988) is the first paper to derive the particular set of preferences that allows for a balanced growth path property.

The underlying philosophy is centered around the argument that an equilibrium will not exist unless the labour supply decision is independent of the nonstationary path followed by the economy. By implying a cancellation of the income and substitution effects arising from productivity shocks, the admissible class of preferences will maintain the assumption that the boundness of hours is not violated along the balanced growth path. King et al. (1988) show that a multiplicatively separable utility function (with a CRRA consumption term) meets this requirement : $U(C_t, L_t) = \frac{C_t^{1-\sigma}}{1-\sigma}v(L_t)$, if the inverse elasticity of intertemporal substitution $\sigma \neq 1$ and $U(C_t, L_t) = \ln(C_t) + v(L_t)$ if $\sigma = 1$.[17] In a contemporaneous paper, Greenwood et al. (1988) derive an alternative preference structure (GHH) that has the same property. Examples in this direction include the real business cycles models of Mendoza (1991), Neumeyer and Perri (2005) and Aguiar and Gopinath (2007).

If the study of business cycles in nonstationary environments aims to preserve the canonical representation of the New Keynesian model, where the marginal utility of consumption and the dynamic IS curve are independent of the labour supply decision, then additional preference restrictions may be necessary.[18] For instance, there is a unique value of the elasticity of intertemporal substitution ($\sigma = 1$) that meets the above requirements, while also maintaining the balanced growth path property.[19]

1.2.3 Households

The representative consumer has preferences defined over aggregate consumption and disutility of labour, which enter the period return function additively. The specification is a particular case of the admissible set of preferences in King et al. (1988), where the intertemporal elasticity of substitution is restricted to 1. The parameter choice is motivated by the stationarity-inducing transformation which will be discussed later.

$$\max U = E_0 \sum_{t=0}^{\infty} \beta^t \Big[\ln(C_t) - \frac{L_t^{1+\eta}}{1+\eta}\Big] \tag{1.1}$$

To maintain the analytical tractability of the model, a unitary elasticity of substitution between traded ($C_{T,t}$) and nontraded ($C_{N,t}$) consumption goods is assumed. Hence, the

[17] When $\sigma \geq 1$, the function v is increasing and concave, whereas in the case of $\sigma < 1$, v is decreasing and convex.

[18] See Ireland (2004b) for a discussion. Schmitt-Grohé and Uribe (2005), Del Negro et al. (2007), Altig et al. (2005) and Rabanal and Tuesta (2010) are examples of NK models where technological progress has a permanent, nonstationary component.

[19] Most papers that design nonstationary models in the NK tradition impose additive separable preferences, with a logarithmic utility in consumption. An exception is Smets and Wouters (2007).

mapping from the sector specific demands to the final consumption good is done using a Cobb-Douglas aggregator:

$$C_t = \frac{C_{T,t}^{\upsilon} C_{N,t}^{1-\upsilon}}{\upsilon^{\upsilon}(1-\upsilon)^{1-\upsilon}} \tag{1.2}$$

where υ represents the share of total consumption allocated to traded goods. The specification of the aggregate consumption basket, which is homogenous of degree one, increasing in both arguments and concave, implies that traded and nontraded sector goods are normal.

Conditional on the aggregation technology described above, the cost of purchasing the final good is minimised when the representative household allocates its consumption expenditures as:

$$C_{T,t} = \upsilon\Big(\frac{P_{T,t}}{P_t}\Big)^{-1} C_t \tag{1.3}$$

$$C_{N,t} = (1-\upsilon)\Big(\frac{P_{N,t}}{P_t}\Big)^{-1} C_t \tag{1.4}$$

where $P_{T,t}$, $P_{N,t}$ are the corresponding price levels and P_t is:

$$P_t = P_{T,t}^{\upsilon} P_{N,t}^{1-\upsilon} \tag{1.5}$$

Traded sector consumption is defined by a similar CD aggregator, expressed over home (H) and foreign (F) traded goods. In this case, the expenditure share is depicted by the parameter θ.

$$C_{T,t} = \frac{C_{H,t}^{\theta} C_{F,t}^{1-\theta}}{\theta^{\theta}(1-\theta)^{1-\theta}} \tag{1.6}$$

Similarly to equations (1.3)-(1.5), the traded sector demand functions are given by:

$$C_{H,t} = \theta\Big(\frac{P_{H,t}}{P_{T,t}}\Big)^{-1} C_{T,t} = \theta\upsilon\Big(\frac{P_{H,t}}{P_t}\Big)^{-1} C_t \tag{1.7}$$

$$C_{F,t} = (1-\theta)\Big(\frac{P_{F,t}}{P_{T,t}}\Big)^{-1} C_{T,t} = (1-\theta)\upsilon\Big(\frac{P_{F,t}}{P_t}\Big)^{-1} C_t \tag{1.8}$$

$$P_{T,t} = P_{H,t}^{\theta} P_{F,t}^{1-\theta} \tag{1.9}$$

No impediment prevents households from substituting hours worked in one sector with the other. We assume that home traded and nontraded labour services are perfectly substitutable and that each sector specific factor market is competitive. Under these assumptions, aggregate labour supply is additive in $L_{H,t}$ and $L_{N,t}$:

$$L_t = L_{H,t} + L_{N,t} \tag{1.10}$$

To fully specify the consumption-saving decision, the asset market structure needs to be characterised. Households are able to save by holding two one-period bonds, denominated in domestic (B_t^H) and foreign (B_t^F) currencies. In this respect, the framework belongs to the class of imperfect risk sharing models which integrate the current account as an explanatory variable of international business cycles (as in Benigno and Thoenissen, 2003; Benigno, 2009; De Paoli, 2009b; Ghironi, 2006; Kollmann, 2001; Obstfeld and Rogoff, 1995; Rabanal and Tuesta, 2010; Selaive et al., 2003). When risk-sharing is imperfect across countries, idiosyncratic shocks will generally have a permanent effect on the optimal holding of the foreign bond. The latter also stands for the net foreign assets position in the model. Unless some equilibrating mechanism is introduced (Schmitt-Grohé and Uribe, 2003; Uribe, 2011), wealth effects arising from asset accumulation will render the net foreign assets position indeterminate and this inconvenient property will be transmitted to other variables in the system.

To deal with the unit root problem, we assume that steady state deviations of the normalised net foreign assets position are reflected in a risk-premium term Ω_t which depends on the sign and size of the deviation.[20] Following Benigno (2009), Benigno and Thoenissen (2008), Ambler, Dib, and Rebei (Ambler et al.) and Rabanal and Tuesta (2010), Ω_t is assumed to have a debt elastic functional form : $ln\Omega_t = -\xi\left(\frac{S_t B_t^F}{P_{H,t}Y_t} - \bar{b}\right)$. The parameter ξ measures the proportional increase in the risk premium when the net foreign assets position deviates from its sustainable level. Nominal bond holdings are normalised with respect to aggregate output, Y_t, and its associated price $P_{H,t}$. Note that the price of output is different from the price of consumption, as Y_t is defined in terms of the traded good numeraire.

The maximisation of the lifetime utility function in (1.1) is done with respect to the sequence of flow budget constraints specified below:

$$C_t + \frac{B_t^H}{P_t(1+i_t)} + \frac{S_t B_t^F}{P_t(1+i_t^*)\Omega(\frac{S_t B_t^F}{P_{H,t}Y_t})} \leq \frac{B_{t-1}^H}{P_t} + \frac{S_t B_{t-1}^F}{P_t} + \frac{W_{H,t}L_{H,t}}{P_t} + \frac{W_{N,t}L_{N,t}}{P_t} + \frac{\Pi_t}{P_t} \tag{1.11}$$

On the optimal path of consumption, labour and domestic and foreign bond holdings, a

[20] For a full discussion on the alternative mechanisms that can be used to deal with the indeterminacy of the net foreign assets position, the reader is referred to Ghironi (2008) and Schmitt-Grohé and Uribe (2003).

set of first order conditions must be satisfied:

$$\Lambda_t = \frac{1}{C_t} \tag{1.12}$$

$$\Lambda_t = E_t[\beta(1+i_t)\frac{P_t}{P_{t+1}}\Lambda_{t+1}] \tag{1.13}$$

$$w_t = -\frac{U_L(C_t, L_t)}{\Lambda_t} = \frac{L_t^\eta}{\Lambda_t} \tag{1.14}$$

$$E_t\Big[m_{t+1}[(1+i_t^*)\Omega(.)\frac{S_{t+1}}{S_t} - (1+i_t)]\Big] = 0 \tag{1.15}$$

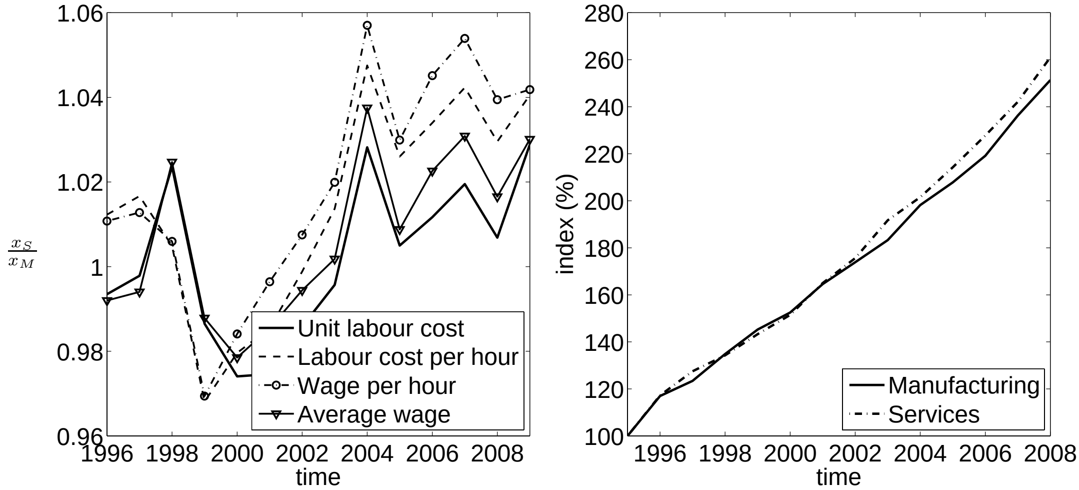
where the following notation has been used: Λ_t is the marginal utility of consumption, $w_t = \frac{W_t}{P_t}$ represents the real wage rate, while $m_{t+1} = \beta\frac{\Lambda_{t+1}}{\Lambda_t}\frac{P_t}{P_{t+1}}$ defines the stochastic discount factor.

In equation (1.14), perfect substitutability of labour supply across sectors implies nominal wage equalisation: $W_{H,t} = W_{N,t} = W_t$. The assumption of internal labour mobility is a vital element to the foundation of the Balassa-Samuelson theory, as most of the results critically depend on the implied transmission mechanism. Two reasons have been advanced to support the equalisation of factor prices (Begg et al., 2003). On the one hand, asymmetric productivity gains can be interpreted as incentives to acquire additional skills, that are relevant in the expanding sector. This enables workers to seek access to better paid jobs. Even if the relocation process is imperfect, these forces will tend to equalise wages across the economy in the medium to long-run. On the other hand, trade unions might prevent the emergence of substantial discrepancies. Since the dependence on the labour mobility assumption is a common critique to the original BS proposition, we present the historical observations of four commonly adopted measures of labour costs in the Czech Republic. The graphs depicted in figure 1.3 reveal that the differences between average and hourly wages in manufacturing and services are minor.

1.2.4 Production and Price Setting

The traded and nontraded sectors of the economy are populated by two continua of intermediate good producers, who operate in monopolistically competitive market structures. Their output is combined into final goods, indexed by H and N, that are supplied as bundles of differentiated products directly to consumers.

Following the recent monetary economics literature, the model is solved for the general case of a distorted steady state. Hence, we refrain from allowing the government to



(a) relative labour costs (b) average wage index

Figure 1.3: Czech Republic : relative costs of labour in services and manufacturing

implement a production subsidy through which it can eliminate the distortion caused by the presence of monopoly power in product markets. As intermediate good producers have a certain degree of market power, they set the optimal price for their products by solving an intertemporal problem in the presence of nominal rigidities. We describe in turn the problem faced by each type of agent.

1.2.4.1 The Representative Final Good Producer

Let the quantities supplied by intermediate good producers be defined by $Y_t(h)$ and $Y_t(n)$, with varieties h, n indexed on the unit interval, and let the elasticities of substitution among goods belonging to the same class be represented by $\phi, \varphi > 1$. Then, the sector specific final goods are obtained using the CES aggregators:

$$Y_{H,t} = \left[\int_0^1 Y_t(h)^{\frac{\phi-1}{\phi}} dh \right]^{\frac{\phi}{\phi-1}} \tag{1.16}$$

$$Y_{N,t} = \left[\int_0^1 Y_t(n)^{\frac{\varphi-1}{\varphi}} dn \right]^{\frac{\varphi}{\varphi-1}} \tag{1.17}$$

Minimising the total cost of supplying one unit of the final good results in the following factor demands:

$$Y_t(h) = \left[\frac{P_t(h)}{P_{H,t}} \right]^{-\phi} Y_{H,t} \ , \qquad Y_t(n) = \left[\frac{P_t(n)}{P_{N,t}} \right]^{-\varphi} Y_{N,t} \tag{1.18}$$

where the sector price indexes,$P_{H,t}$ and $P_{N,t}$, are defined by:

$$P_{H,t} = \left[\int_0^1 P_t(h)^{1-\phi} dh \right]^{\frac{1}{1-\phi}}, \qquad P_{N,t} = \left[\int_0^1 P_t(n)^{1-\varphi} dn \right]^{\frac{1}{1-\varphi}} \tag{1.19}$$

1.2.4.2 Intermediate Good Producers

The production of individual goods is carried out according to CRTS technologies, augmented with the nonstationary productivity variables Γ:

$$Y_t(h) = \Gamma_{H,t} L_t(h) \tag{1.20}$$

$$Y_t(n) = \Gamma_{N,t} L_t(n) \tag{1.21}$$

The dynamic paths followed by Γ_H and Γ_N establish the theoretical foundation of our experiments. Whereas the nontraded sector grows at the same rate as the foreign economy, we allow for a highly persistent convergence shock in the open sector. The asymmetric growth between the manufacturing and service sectors creates a close parallel to the stylised fact we established in figure 1.1 for the Czech Republic. The properties of the two exogenous variables also constitute the lense through which we model the effects of asymmetric productivity growth on the monetary policy design problem. It is important to mention that agents have perfect foresight, being able to fully anticipate the future movements of the productivity variables.

The foreign and nontraded sector trends (Γ_t^*, $\Gamma_{N,t}$) increase at a constant rate g^*:

$$\Gamma_t^* = (1 + g^*)\Gamma_{t-1}^* \tag{1.22}$$

$$\Gamma_{N,t} = (1 + g^*)\Gamma_{N,t-1} \tag{1.23}$$

where the growth rate in the nontraded sector is equal to g^* for simplicity.[21]

On the other hand, the dynamic process of $\Gamma_{H,t}$ is specified such that it generates a persistent productivity growth differential between the traded and nontraded sectors:

$$1 + g_{H,t} = \varrho(1 + g_{H,t-1}) + (1 - \varrho)(1 + g^*) \tag{1.24}$$

[21] As a result of this restriction, the growth differentials between the traded and nontraded sectors and the domestic-foreign economy can be interpreted interchangeably.

The stance we take on modelling the real convergence phenomenon corresponds to the specifications adopted by Masten (2008) and Ravenna and Natalucci (2008). Traded sector productivity growth jumps in the initial period following a one-time shock. The subsequent adjustment process is governed by the persistence parameter ϱ, which models the rate at which the convergence effects caused by European integration decline over time. Alternatively, equation (1.24) can be thought of as a deterministic autogressive process, where domestic productivity growth slowly reverts to the long term mean g^* at a constant rate. By choosing empirically sensible values for the size of the initial shock and the persistence parameter, the dynamic equation of g_H can be used to simulate various catch-up scenarios, that are independent of the initial productivity gap. The economic interpretation behind the adjustment process is that factors such as technology transfers, immitation of more efficient production methods and a gradual alignment of institutions cause an excess productivity growth in the present, via their effect on total factor productivity.

It is possible, however, to design an alternative approach to modelling the convergence phenomenon, by specifying an adjustment process of the relative productivity *levels*. In this case the parameterisation has a different interpretation, for it involves the long-term mean of the relative productivity ratio (μ) and the speed of adjustment at which the process takes place $(1-\omega)$:

$$(X_t - \mu) = \omega(X_{t-1} - \mu) \tag{1.25}$$

where $X_t = \frac{\Gamma_{H,t}}{\Gamma_t^*}$ denotes the domestic traded - foreign productivity gap at time t.

Both (1.24) and (1.25) are first order difference equations that imply a nonlinear path of the traded sector growth rate. The inherent error correction mechanism associated with such processes predicts that deviations from the mean are corrected more rapidly when the variables are further away from their long run equilibrium values. Consequently, both specifications are consistent with the notion of β-convergence in the growth literature (Barro and Sala-i Martin, 1990), which assumes that poor countries tend to improve their standards of living at higher rates in the initial periods. However, the two processes are completely different and do not imply each other, even when the parameters are calibrated such that the size of the initial growth increase and long-term means are identical. This effect is a consequence of the dependence of $g_{H,t}$ on the current relative productivity level in equation (1.25). The details of implementing the alternative specification in the context of our model are further explored in Chapter 2.

One advantage of relating to growth differentials, rather than productivity levels, is that the former do not impose a prior mean on the *long-run relative per capita income levels*. As real convergence is likely to occur in gradual steps, separated by periods of relative stagnation (e.g. during a global financial crisis), this adjustment scenario can offer more general policy advice. In other words, a convergence episode from 60% to 70% of the euro area income per capita level is treated similarly to an income convergence of the same magnitude that starts at 10 percentage points higher.

Moreover, the sources of real convergence we address, which do not include capital accumulation, are unlikely to lead to a full alignment of the standards of living. Even in a world where technology can be diffused at no cost across borders, productivity differences might still exist, as Acemoglu and Zilibotti (2001) argue. The partial convergence prediction of their paper is based on the technology-skill mismatches that are likely to arise, once the technological leader develops new innovations that serve its country-specific needs. In light of these observations, it is not surprising that other real convergence simulations (Carone et al., 2006; Wagner and Hlouskova, 2005) have taken a more conservatory view on the long-run relative productivity ratios between the Czech Republic and the euro area.

Further notation is introduced by defining an economy wide trend variable Γ_t, that will be used for rendering the model stationary:

$$\Gamma_t = (\Gamma_{H,t})^{\upsilon\theta}(\Gamma_t^*)^{\upsilon(1-\theta)}(\Gamma_{N,t})^{1-\upsilon}$$

The economy-wide trend grows at the rate :

$$1 + g_t = (1 + g_{H,t})^{\upsilon\theta}(1 + g^*)^{\upsilon(1-\theta)}(1 + g_N)^{1-\upsilon} = (1 + g_{H,t})^{\upsilon\theta}(1 + g^*)^{1-\upsilon\theta} \tag{1.26}$$

Several factors can account for the heterogenous productivity growth characteristics of the Czech economy. One potential explanation is the nature of FDI inflows, which are mainly oriented towards industries open to international trade. Foreign ownership of domestic companies is accompanied by transfers of managerial expertise, improvements in corporate governance and access to more efficient ways of producing goods. All these factors support the plausible argument for why productivity convergence in the traded sector takes place.

The empirical evidence also endorses the nature of productivity driven catch-up we assume. For example, the relationship between FDI and productivity convergence is tested for in Bijsterbosch and Kolasa (2010), who find that FDI is an important factor in accounting for productivity growth in Central and Eastern European economies. Moreover, their results at the industry level suggest that productivity catch-up occurs mainly in the manufacturing sector, which is a commonly adopted measure of traded goods. Intra-industry diffusion effects arising from FDI in the Czech Republic are also found in a recent study by Kosova (2010), who uses firm level data and a better estimation procedure compared to the previous literature.

It might be argued that ignoring stochastic elements in our model constitutes a substantial drawback, as the framework we propose detaches itself from the established DSGE literature. There are, however, important reasons that underline our decision. The first element is the impossibility to derive a nonstationary efficient allocation, given the convex dynamic path followed by the traded sector growth rate (see figure 1.4). The main assumption that creates technical difficulties in this sense is the presence of incomplete asset markets, which limits considerably the range of policy experiments implementable in a stochastic environment (see Corsetti et al., 2008b, p.452-453, for a related discussion). In this sense, Kollmann (2002, p.998) concludes that the Ramsey problem is intractable in a stochastic SOE model. For the high magnitude of the convergence shock we assume, standard perturbation techniques become inaccurate. As an alternative approach, a potential solution would be to use projection methods, by discretising the state-space and assume a finite number of realisations of the stochastic variables. One example in this direction is the canonical RBC-SOE incomplete markets model proposed by Mendoza (1991), who assumes that the stochastic disturbances are Markov chains. The theoretical structure in that paper is greatly simplified however, as there is only one sector and nominal variables are ignored. We argue that the large number of state variables that exist in our model makes the application of projection techniques hard, if not impossible. In light of the above limitations, the only feasible alternative is to compute the optimal Ramsey plan under perfect foresight. The solution, in this case, becomes globally valid even when the supply-side adjustments are relatively large.

Second, the focus of the exercise we conduct relative to the DSGE literature is different. In our case, the monetary policy design problem is judged in relation to an anticipated productivity convergence process and not in connection to the stochastic structure of the economy. Moreover, the magnitude of the anticipated dynamics of the productivity variable is likely to dominate the effects of stochastic shocks.

Finally, the perfect foresight assumption has a meaningful advantage over the perturbation techniques employed in stochastic economies, as it allows the simulation of the fully nonlinear model. In constrast, the presence of large disturbances causes the approximation errors to be quite large in the case of local solution methods. In consideration of the deterministic solution we adopt, the conditional expectations operator will be dropped from the remaining structural equations.

1.2.4.3 Price Setting with Rotemberg Adjustment Costs

Intermediate firms choose a sequence of prices in each period to maximise discounted lifetime profits. Nominal rigidities in the goods market are introduced in the form of making price adjustment costly. In this sense, the paper follows Rotemberg (1982) in assuming that price setting is subject to quadratic adjustment costs.[22] In nominal terms, the optimisation problem of a traded sector firm can be written as:

$$\max_{P_{t+s}(h)} \sum_{s=0}^{\infty} \beta^s \frac{C_t}{C_{t+s}} \frac{P_t}{P_{t+s}} \Big[P_{t+s}(h) \Big(\frac{P_{t+s}(h)}{P_{H,t+s}} \Big)^{-\phi} Y_{H,t+s} - \Psi_{H,t+s} \Big(\frac{P_{t+s}(h)}{P_{H,t+s}} \Big)^{-\phi} Y_{H,t+s} - \\ - \frac{\psi_H}{2} \Big(\frac{P_{t+s}(h)}{\pi_H P_{t+s-1}(h)} - 1 \Big)^2 P_{H,t+s} Y_{H,t+s} \Big]$$

where $\Psi_{H,t+s} = \frac{W_{t+s}}{\partial Y_{t+s}(h)/\partial L_{H,t+s}}$ is the nominal marginal cost, common among firms, and π_H represents the balanced growth path rate of inflation.[23]

After associating the gross rates of inflation with π_t and $\pi_{H,t}$, the optimal price setting path can be described as:

$$(1-\phi) \Big(\frac{P_t(h)}{P_{H,t}} \Big)^{1-\phi} Y_{H,t} + \phi \Psi_{H,t} \Big(\frac{P_t(h)}{P_{H,t}} \Big)^{-\phi} \frac{Y_{H,t}}{P_t(h)} - \psi_H \Big(\frac{\pi_t(h)}{\pi_H} - 1 \Big) \frac{1}{\pi_H P_{t-1}(h)} P_{H,t} Y_{H,t} - \\ - \beta \frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \psi_H \Big(\frac{\pi_{t+1}(h)}{\pi_H} - 1 \Big) \frac{\pi_{t+1}(h)}{\pi_H} \Big(- \frac{P_{H,t+1}}{P_t(h)} \Big) Y_{H,t+1} = 0$$

Since the price setting problem is homogenous across firms, which have access to the same production function and are subject to uniform demand constraints and adjustment costs, the individual optimal price corresponds to the sector average ($P_t(h) = P_{H,t}$). Moreover, the symmetry equally applies to output and labour demanded : $Y_t(h) = Y_{H,t}$, $L_t(h) = L_{H,t}$. As firms adjust their current price with respect to expected future demand and cost conditions, the optimal price setting is forward looking:

$$\phi - 1 = \phi mc_{H,t} - \psi_H \Big(\frac{\pi_{H,t}}{\pi_H} - 1 \Big) \Big(\frac{\pi_{H,t}}{\pi_H} \Big) + \beta \psi_H \frac{C_t}{C_{t+1}} \frac{1}{\pi_{t+1}} \Big(\frac{\pi_{H,t+1}}{\pi_H} - 1 \Big) \Big(\frac{\pi_{H,t+1}}{\pi_H} \Big) \pi_{H,t+1} \frac{Y_{H,t+1}}{Y_{H,t}} \tag{1.27}$$

where the real marginal cost has been defined by:

$$mc_{H,t} = \frac{\Psi_{H,t}}{P_{H,t}} = w_t \Big(\frac{P_t}{P_{H,t}} \Big) \frac{1}{\Gamma_{H,t}} \tag{1.28}$$

Along a balanced growth path with a constant rate of inflation, equation (1.27) simplifies

[22] See Bergin (2003) for an alternative specification of the adjustment costs.
[23] Or alternatively, the inflation rate at which there are no adjustment costs in changing prices.

to a standard flexible price relationship between the real marginal cost and the markup ($mc_{H,t} = \frac{\phi-1}{\phi}$).

The price setting optimisation problem in the nontraded sector results in a similar expression:

$$\varphi - 1 = \varphi mc_{N,t} - \psi_N \Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)\Big(\frac{\pi_{N,t}}{\pi_N}\Big) + \beta\psi_N \frac{C_t}{C_{t+1}} \frac{1}{\pi_{t+1}} \Big(\frac{\pi_{N,t+1}}{\pi_N} - 1\Big)\Big(\frac{\pi_{N,t+1}}{\pi_N}\Big)\pi_{N,t+1} \frac{Y_{N,t+1}}{Y_{N,t}} \tag{1.29}$$

with

$$mc_{N,t} = w_t \Big(\frac{P_t}{P_{N,t}}\Big)\frac{1}{\Gamma_{N,t}} \tag{1.30}$$

1.2.5 Relative Price Expressions and the Real Exchange Rate

Let the terms of trade and the relative price of nontraded goods be defined as:

$$T_t = \frac{P_{F,t}}{S_t P^*_{H,t}} = \frac{S_t P^*_{F,t}}{P_{H,t}} = \frac{P_{F,t}}{P_{H,t}} \tag{1.31}$$

$$R_t = \frac{P_{N,t}}{P_{T,t}} \tag{1.32}$$

In deriving the alternative representations of T_t, we have implicitly assumed that the cost of purchasing the two homogenous goods is equal in different markets: $S_t P^*_{H,t} = P_{H,t}$ and $S_t P^*_{F,t} = S_t P^*_t = P_{F,t}$. This view corresponds to the traditional interpretation of the macroeconomic adjustment in open economies and underlies the producer currency pricing (PCP) strand of the literature.[24] It is well known that, when the law of one price holds for traded goods and prices are set in the currency of the producer, movements in international relative prices are fully reflected in the price of imported goods (e.g. exchange rate pass-through is complete). Under these circumstances, many analyses dating back to Friedman (1953) have argued that optimal monetary policy should rely on exchange rate flexibility. This is because, with imperfect price adjustment in both countries, movements in the nominal exchange rate are able to shift the terms of trade towards the efficient level needed to counterbalance the effects of country-specific productivity shocks. For instance, monetary policy expansions lower the value of the domestic currency and result in a terms of trade deterioration for the home country. Since domestic products are cheaper both at home and abroad, changes in relative prices give rise to expenditure switching effects that redirect global demand towards domestic goods.

[24] See Clarida et al. (2001), Benigno and Benigno (2003), Gali and Monacelli (2005) or Benigno (2009) for examples.

Despite its popularity in Keynesian and Mundell-Fleming analyses, the assumption of full exchange rate pass-through has generated intense debates in academic circles over the past decade. Nowadays, there is a general consensus that international relative price movements are only partially reflected in the price of imported goods over the short run, leading to persistent deviations from the law of one price (Atkeson and Burstein, 2008; Campa and Goldberg, 2005; Goldberg and Knetter, 1997). As prices are rather stable in the currency of the destination market, the expenditure switching effects envisaged by Friedman appear not to be so strongly supported in the data. The precise causes for the local currency stability of imports are subject to ongoing research, mainly because this stylised fact can be explained by both nominal and real factors.

An increasing number of papers have attributed the low degree of exchange rate pass-through solely to nominal rigidities, by assuming local currency pricing (LCP).[25] The alternative view on the international macroeconomic adjustment states that export prices are quoted in the currencies of the destination market. Because prices are sticky at the local level and invoicing practices are country-specific, firms are able to price discriminate across different markets. As a result and consistent with the empirical evidence, the law of one price does not generally hold in the short-run and pass-through is incomplete. Local currency pricing breaks down the equivalence between the terms of trade and the relative price of imports faced by each type of consumer, in that the ratios $\frac{P_{F,t}}{S_t P^*_{H,t}}$, $\frac{P^*_{F,t}}{P^*_{H,t}}$ and $\frac{P_{F,t}}{P_{H,t}}$ have different values. From a modelling perspective, this requires that four dynamic equations for domestic and foreign prices be specified.[26] Rather than triggering the desirable expenditure effects predicted by the PCP approach, exchange rate movements cause deviations from the law of one price and may represent a source of suboptimality in these models. In essence, any price discrepancy that occurs even if the marginal cost of supplying a homogeneous product is equal in different markets gives rise to an inefficient allocation. Engel (2011) shows that the case for inward looking policies and exchange rate flexibility is no longer supported under a LCP environment, as optimal monetary policy should target currency misalignments in addition to inflation and output goals.

The merits of this literature are twofold. On the one hand, it provides potential explanations for well known puzzles in international economics. For instance, Betts and Devereux (2000) and Devereux and Engel (2002) demonstrate that open-economy models incorporating the LCP paradigm can replicate important empirical regularities such as the high volatility and persistence of real exchange rates, thereby addressing the exchange rate

[25] An incomplete list of papers includes Bacchetta and Van Wincoop (2000), Betts and Devereux (2000), Chari et al. (2002), Devereux and Engel (2002) and Corsetti and Pesenti (2005). Particularly insightful for understanding the differences between the macroeconomic adjustment under PCP and LCP are the contributions by Devereux and Engel (2003), Corsetti et al. (2010) and Engel (2011).

[26] See Kollmann (2002) for a small open economy example.

disconnect puzzle.[27] On the other hand, it requires central banks to carefully judge the effects of their policy decisions on the economy, as these may have completely different transmission mechanisms than previously thought. With local currency price stability, a monetary expansion has a minimal influence on the relative price of imports and does not induce consumers to switch demand towards domestic goods. In contrast to the PCP case, a nominal depreciation always induces a real exchange rate depreciation and increases the receipts of home firms selling goods abroad. Because domestic residents have higher purchasing power, the terms of trade tend to improve, rather than deteriorate, under these circumstances (Corsetti et al., 2010). In light of the positive exchange rate-terms of trade correlation observed in the data, Obstfeld and Rogoff (2000) have used the above prediction to claim that models employing only LCP to account for imperfect pass-through are highly implausible. Although neither of the two extreme invoicing assumptions is entirely realistic, there is some truth in both. Recent developments in the field (Goldberg and Tille, 2008; Gopinath et al., 2010) suggest that the currency choice by firms engaged in international trade is an endogenous decision and went on to study its determinants at both a theoretical and empirical level.

From a broader perspective, deviations from the law of one price can arise independently of nominal rigidities when real factors (e.g. distribution services, rents and other nontraded components of final goods, country specific markup adjustment by firms) are accounted for. Relevant in this sense are the findings by Nakamura and Zerom (2010), who analyse the determinants of incomplete pass-through in the coffee industry. Their findings reveal that local costs and the markup adjustment are key determinants of incomplete pass-through, whereas menu costs have a negligible influence. Motivated by the above evidence, the research agenda should evolve towards developing structural models with intermediate nontraded inputs, which, in our view, are more capable at reconciling their implied dynamics with the facts. An important step in this direction is made by the model in Corsetti et al. (2008a), whose dynamics are consistent with low pass-through *and* a positive correlation between international relative prices and the terms of trade. Moreover, their framework equally addresses the disconnect puzzle, for it generates highly volatile real exchange rate movements.

In light of the previous discussion, it is clear that the PCP assumption is too narrow for certain empirical purposes and we acknowledge its limitations. This feature of the model is kept mainly for analytical convenience and in order to enable a direct comparison with the relevant literature (Masten, 2008; Ravenna and Natalucci, 2008). Needless to say, the analysis can be extended to account for local currency price stability and this would

[27] Bergin (2006) estimates a two country model using maximum likelihood methods and finds empirical support for local currency pricing.

certainly result in a more realistic real convergence environment.

Rearranging (1.31) for S_t, we obtain that :

$$\frac{S_t}{S_{t-1}} = \frac{\pi_{H,t}}{\pi_t^*}\frac{T_t}{T_{t-1}}$$

Using the last equation, the risk-adjusted UIP condition in (1.15) translates to :

$$\beta\frac{\Lambda_{t+1}}{\Lambda_t}\frac{1}{\pi_{t+1}}[(1+i_t^*)\Omega(.)\frac{T_{t+1}}{T_t}\frac{\pi_{H,t+1}}{\pi_{t+1}^*} - (1+i_t)] = 0 \tag{1.33}$$

To ease notation further, we derive the expressions of a set of relative price terms :

$$\frac{P_{N,t}}{P_t} = \frac{P_{N,t}}{P_{T,t}R_t^{1-\upsilon}} = R_t^{\upsilon} \tag{1.34}$$

$$\frac{P_{T,t}}{P_t} = \frac{P_{T,t}}{P_{T,t}R_t^{1-\upsilon}} = R_t^{\upsilon-1} \tag{1.35}$$

$$\frac{P_{H,t}}{P_t} = \frac{P_{H,t}}{P_{T,t}}\frac{P_{T,t}}{P_t} = \frac{P_{H,t}}{P_{H,t}T_t^{1-\theta}}R_t^{\upsilon-1} = T_t^{\theta-1}R_t^{\upsilon-1} \tag{1.36}$$

$$\frac{P_{F,t}}{P_t} = \frac{P_{F,t}}{P_{T,t}}\frac{P_{T,t}}{P_t} = \frac{P_{F,t}}{P_{H,t}T_t^{1-\theta}}R_t^{\upsilon-1} = T_t^{\theta}R_t^{\upsilon-1} \tag{1.37}$$

$$R_t = \frac{P_{N,t}}{P_{T,t}} = \left(\frac{P_{N,t}}{P_{H,t}}\right)\frac{1}{T_t^{1-\theta}} = R_{NH,t}T_t^{\theta-1} \tag{1.38}$$

Note that the internal price ratio $R_{NH,t} = \frac{P_{N,t}}{P_{H,t}}$ is closely related to the ratio of real marginal costs. To see this, divide equations (1.28) and (1.30) to obtain:

$$R_{NH,t} = \left(\frac{mc_{H,t}}{mc_{N,t}}\right)\left(\frac{\Gamma_{H,t}}{\Gamma_{N,t}}\right)$$

Because the dynamic path of $R_{NH,t}$ can only be pinned down in terms of its steady state value and the path of inflation, the relative price term is added to the model's structural equations as a new state variable:

$$R_{NH,t} = R_{NH,t-1}\frac{\pi_{N,t}}{\pi_{H,t}} \tag{1.39}$$

The alternative formulations of $R_{NH,t}$ make transparent the reasons why inflation in the service sector will be relatively higher. Since factor markets are competitive, the convergence shock will proportionally increase the marginal product of labour in the traded sector. Because nominal wages are equalised across the economy and real marginal costs are stationary, the only adjustment mechanism possible compatible with the assumption of perfect labour mobility is to have a relatively higher inflation rate in the nontraded sector.

An open economy study would be incomplete without a description of international relative prices. We show below how the real exchange rate relates to the terms of trade and the internal price ratio. This decomposition will prove very useful for understanding the mechanics of the Balassa-Samuelson effect and for presenting some building blocks of the model in a more convenient way.

The real exchange rate is defined as the relative cost of domestic and foreign baskets of goods, when converted into a common currency.

$$Q_t = \frac{S_t P_t^*}{P_t}$$

Since the home economy is small and domestic agents act as price takers in international markets, we abstract from differences that would otherwise exist in the foreign internal price ratios. Based on these premises, all foreign goods are assumed to be nontraded ($\upsilon^* = 0$), whereas domestic goods receive a negligible role in the foreign consumption index. The latter behaves as if $P_{F,t}^* = P_t^*$.[28] When the above simplifications are taken into account, Q_t can be expressed as :

$$Q_t = \frac{S_t P_t^*}{P_t} = \frac{S_t P_{F,t}^*}{P_t} = \frac{P_{F,t}}{P_t} = T_t^{\theta} R_t^{\upsilon-1} \tag{1.40}$$

Another important structural equation is that of CPI inflation. From (1.5) and (1.38), π_t becomes:

$$\pi_t = \pi_{H,t}^{\upsilon} \pi_{N,t}^{1-\upsilon} \left(\frac{T_t}{T_{t-1}} \right)^{(1-\theta)\upsilon} \tag{1.41}$$

Hence, changes in aggregate inflation occur as a result of movements in domestic producer prices (π_N and π_H) and variations in the terms of trade.

1.2.6 Market Clearing Conditions

To close the model, a set of market clearing conditions must hold. In the goods market, the presence of adjustment costs creates a wedge between consumption and output. For

[28] See Gali and Monacelli (2005); Leith and Wren-Lewis (2007); Monacelli (2006) for similar assumptions.

nontraded goods, this implies that:

$$Y_{N,t} = C_{N,t} + \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2 Y_{N,t} \tag{1.42}$$

Hence, the demand for nontraded output equals its supply, adjusted by a lump sum output loss created by the presence of price adjustment costs.

A similar relation holds for the traded sector.[29] The main difference is that part of production is sold abroad, creating the need to specify the functional form of foreign demand for domestic goods ($C^*_{H,t}$).

$$Y_{H,t} = C_{H,t} + C^*_{H,t} + \frac{\psi_H}{2}\Big(\frac{\pi_{H,t}}{\pi_H} - 1\Big)^2 Y_{H,t} \tag{1.43}$$

As the economy is small and home producers do not have market power in international markets, the market share of domestic goods in the foreign markets will be relatively low. Hence, the structural equations of the rest of the world correspond to a closed economy, meaning that foreign levels of aggregate consumption and output are equivalent ($Y^*_t = C^*_t$). The technique we use for imposing a small open economy specification follows Adolfson et al. (2007); Monacelli (2004, 2006) and Justiniano and Preston (2010b), being entirely consistent with the alternative approaches found in the literature.[30,31] In light of our previous discussion, the foreign demand for domestic goods is a function of terms of trade and foreign output, being the corresponding equivalent of (1.8). The functional form we adopt is standard (see Clarida et al., 2001; Monacelli, 2006; Smets and Wouters,

[29] A well defined model has to impose the restrictions $\pi_{j,t} \in [\pi_j(1 - \sqrt{\frac{2}{\psi_j}}); \pi_j(1 + \sqrt{\frac{2}{\psi_j}})], j \in \{H, N\}$. If inflation deviates from the above intervals, the economic constraint of positive consumption values in the two sectors will be violated.

[30] For instance, Batini et al. (2007); Sutherland (2005) and De Paoli (2009b) model the world economy as a continuum of agents indexed on the unit interval, with domestic agents being distributed in $[0, n]$. In order to impose the small open economy limiting case ($n \to 0$), the authors assume that the foreign market shares are a function of the degree of openness and the relative sizes of the two economies. The resulting foreign demand for home goods is identical to equation (1.44), the only difference being that the parameter $(1 - \theta^*)$ is interpreted as the degree of openness. Even though the economy is small, domestic exports measured in terms of domestic output will not be 0, as it is emphasised in Batini et al. (2007, section 5.2.6). An alternative approach is followed by Gali and Monacelli (2005), who assume a world economy composed of a continuum of small open identical countries. However, the description of the foreign block in Gali and Monacelli (2005) is identical to the two country approach mentioned earlier, mainly because of the foreign representative agent assumption.

[31] It is worth stressing that the domestic economy is in essence semi-small, since it allows some degree of market power to domestic producers. As it is argued in Justiniano and Preston (2010a), the same modelling strategy is followed by every small open economy study in the NK tradition, including the canonical model of Gali and Monacelli (2005).

2002).

$$C^*_{H,t} = (1-\theta^*)\Big(\frac{P^*_{H,t}}{P^*_t}\Big)^{-1} C^*_t = (1-\theta^*)\Big(\frac{S_t P^*_{H,t}}{S_t P^*_t}\Big)^{-1} Y^*_t = (1-\theta^*) T_t Y^*_t \tag{1.44}$$

On the financial side of the model, foreign agents are restricted from trading domestic currency denominated bonds, which are in zero net supply.

$$B^H_t = 0 \ , \qquad \forall t \tag{1.45}$$

Based on the definition of output, the resource constraint in equation (1.11) can be represented in a complementary manner:

$$\begin{aligned} \frac{B_t}{(1+i^*_t)\Omega(.)} &= \frac{Q_t}{Q_{t-1}}\frac{1}{\pi^*_t}B_{t-1} + \frac{P_{H,t}Y_{H,t} + P_{N,t}Y_{N,t}}{P_t} - \frac{\psi_H}{2}\Big(\frac{\pi_{H,t}}{\pi_H} - 1\Big)^2 \frac{P_{H,t}}{P_t} Y_{H,t} \\ &- \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2 \frac{P_{N,t}}{P_t} Y_{N,t} - C_t \\ &= \frac{Q_t}{Q_{t-1}}\frac{1}{\pi^*_t}B_{t-1} + \frac{P_{H,t}}{P_t}\Big[\Big(1 - \frac{\psi_H}{2}(\frac{\pi_{H,t}}{\pi_H} - 1)^2\Big)Y_{H,t} + R_{NH,t}\Big(1 - \frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N} - 1)^2\Big)Y_{N,t}\Big] - C_t \\ &= \frac{Q_t}{Q_{t-1}}\frac{1}{\pi^*_t}B_{t-1} + \frac{P_{H,t}}{P_t}Y_t - C_t \end{aligned} \tag{1.46}$$

where the variable $B_t = \frac{S_t B^F_t}{P_t}$ denotes real holdings of the foreign bond.

The previous equation captures the law of motion of the net foreign assets position, with the last two terms representing the trade balance. In terms of a standard national accounting relationship, aggregate demand is given by:

$$C_t + TB_t = \frac{P_{H,t}}{P_t} Y_t = \frac{R^v_t}{R_{NH,t}} Y_t \tag{1.47}$$

The dynamic current account equation also introduces a model based measure of aggregate output, Y_t, that is expressed in terms of the tradable good numeraire. The definition we use accounts not only for the price differences across sectors, represented by the variable $R_{NH,t}$, but also for the costs of nominal adjustment:

$$Y_t = \Big[1 - \frac{\psi_H}{2}\Big(\frac{\pi_{H,t}}{\pi_H} - 1\Big)^2\Big]Y_{H,t} + R_{NH,t}\Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2\Big]Y_{N,t} \tag{1.48}$$

It is important to observe that in an open economy environment the price of output will not correspond, in general, to the price of consumption. Hence, one merit of the aggregate demand relationship is to precisely measure the extent to which the two prices are different, as a function of the variables of the model. The result is a generalisation of the more widely used condition in Gali and Monacelli (2005). Compared to the existing framework, the authors assume international asset market completeness, implying that the trade balance is always in equilibrium ($TB_t = 0$), and the existence of only one sector ($\upsilon = 1$). If the two conditions are imposed on equation (1.47), their result is nested as a special case ($C_t = T_t^{1-\theta} Y_t$).

This completes the description of the domestic block of our model. To this end, Appendix A presents the full list of nonstationary equilibrium conditions. Note that the decentralised solution is conditional on the exogenous processes followed by the foreign variables and the policy instrument i_t. As the economy features three types of trend productivity variables ($\Gamma_{H,t}$, $\Gamma_{N,t}$, Γ_t^*), a set of transformations must be performed in order to render the dynamic system in stationary form. We address these remaining steps below.

1.2.7 The Foreign Economy

The equilibrium conditions in the foreign sector correspond to a standard New Keynesian closed economy model, where, as in Monacelli (2006), the monetary authority aims to replicate the flexible price allocation in each period. The structural equations of the external block are easily obtained as the closed economy equivalent relations of (A.3), (A.4), (A.5) ,(A.13), (A.15), (A.17) and (A.18). It follows that:[32]

$$\Lambda_t^* = \frac{1}{C_t^*} \qquad \Lambda_t^* = \frac{\beta(1+i_t^*)}{\pi_{t+1}^*}\Lambda_{t+1}^* \qquad w_t^* = \frac{L_t^{*\eta}}{\Lambda_t^*}$$

$$Y_t^* = \Gamma_t^* L_t^* \qquad mc_t^* = \frac{\phi - 1}{\phi} = \frac{w_t^*}{\Gamma_t^*} \qquad C_t^* = Y_t^*$$

The foreign monetary authority implements policy such that it stabilises inflation ($\pi_t^* = \pi^*$) and the output gap for all t. By imposing the flexible price allocation on the external block, we obtain a working version of the foreign structural equations that can be summarised by only two conditions. After performing a set of transformations that are analogous to the ones we discuss in the next section, the resulting stationary equilibrium conditions are given by:

$$1 + i^* = \frac{(1+g^*)\pi^*}{\beta} \tag{1.49}$$

$$y^* = \left[\frac{\phi - 1}{\phi}\right]^{\frac{1}{1+\eta}} \tag{1.50}$$

[32]The reader is referred to Ireland (2004b) for a similar derivation.

1.2.8 Inducing Stationarity

The structural equations of the model describe the dynamic behaviour of a growing economy. One disadvantage of this representation is that the unit root components of $\Gamma_{H,t}$, $\Gamma_{N,t}$ and Γ_t^* are further transmitted to real variables such as consumption, output and the real wage, all of which will inherit the property of being nonstationary. Without performing a set of transformations to the dynamic system, the model cannot be solved. The resulting set of stationary variables will be constant along a balanced growth path once the convergence shock dies out. Accordingly, the objective of this section is to unravel the mapping between the competitive allocations in their nonstationary and stationary representations.

To briefly explain how the transformation procedure is conducted, a first useful observation is that the dynamic paths of inflation, real marginal costs and hours are independent of the nonstationary trends. As a result, these variables do not need to be rescaled. A second general principle is that the sector specific allocations, such as output and consumption, are cointegrated with the corresponding productivity trends. The scaling of these variables can be easily understood by looking at the production functions (A.13)-(A.14) and the market clearing conditions (A.18)-(A.19). Moreover, some economy-wide variables (C_t, TB_t, B_t) are normalised by dividing them with the aggregate productivity trend, Γ_t. The latter was previously defined in equation (1.26). A third observation concerns the transformation of relative prices, which include the terms of trade, the internal price ratio and the real exchange rate. These variables are cointegrated with the inverse common trends that would be needed to render the corresponding relative output levels stationary.[33]

The above principles are applied to express the equilibrium conditions in an equivalent, stationary form. To this end, the full list of transformations we present below provides the mapping between the unnormalised and normalised set of variables that define the decentralised allocation in Appendices A and B. The distinction between nonstationary and scaled variables is made using capital and small letters. Three other notational conventions are adopted. First, the transformed real wage is represented by w_t^d. Second, the change to stationary relative prices is marked using Greek letters. In this sense, the detrended terms of trade and internal price ratio are defined by τ_t and $\rho_{nh,t}$. Finally, hours are represented with small letters, even though they do not need to be transformed.

[33] An intermediate expression we derived for the internal price ratio stated that $R_{NH,t} = \left(\frac{mc_{H,t}}{mc_{N,t}}\right)\left(\frac{\Gamma_{H,t}}{\Gamma_{N,t}}\right)$. Since real marginal costs are stationary, it follows that $R_{NH,t}$ is cointegrated with ratio of traded and nontraded productivity trends. The opposite transformation is necessary to render the corresponding relative output ratio $(\frac{Y_{N,t}}{Y_{H,t}})$ stationary.

Allocations		Relative prices	Untransformed variables
$x_1 = \frac{X_1}{\Gamma_{H,t}}$,	$X_1 = \{C_{H,t}, Y_{H,t}, Y_t\}$	$\tau_t = \frac{\Gamma_t^*}{\Gamma_{H,t}} T_t$	$\pi_{H,t},\ \pi_{N,t},\ \pi_t$
$x_2 = \frac{X_2}{\Gamma_{N,t}}$,	$X_2 = \{C_{N,t}, Y_{N,t}\}$	$\rho_{nh,t} = \frac{\Gamma_{N,t}}{\Gamma_{H,t}} R_{NH,t}$	$L_{H,t},\ L_{N,t},\ L_t$
$x_3 = \frac{X_3}{\Gamma_t}$,	$X_3 = \{C_t, TB_t, B_t\}$	$\rho_t = \frac{\Gamma_{N,t}}{\Gamma_{H,t}^{\theta} {\Gamma_t^*}^{1-\theta}} R_t$	$mc_{H,t},\ mc_{N,t}$
$x_4 = \frac{X_4}{\Gamma_t^*}$,	$X_4 = \{Y_t^*\}$	$q_t = \frac{\Gamma_t^*}{\Gamma_t} Q_t$	
$\lambda_t = \Gamma_t \Lambda_t$		$w_t^d = \frac{w_t}{\Gamma_t}$	

List of transformations

In Appendix C, we address the important question of whether the model can be detrended if a more general CES specification for the traded sector consumption index is assumed. Our proof reveals that a transformation exists only if the model imposes either unitary or infinite values to the trade elasticity of substitution. This important detail has been omitted by Masten (2008), who considered parameterisations of his model that were inconsistent with the rescaling procedure.

1.2.9 Competitive Equilibrium

A competitive equilibrium is a set of prices $\{\pi_{H,t},\ \pi_{N,t},\ \pi_t,\ \tau_t,\ \rho_t,\ \rho_{nh,t},\ q_t,\ w_t^d,\ mc_{H,t},\ mc_{N,t}\}$ and allocations $\{c_{H,t},\ c_{N,t},\ c_t,\ \lambda_t,\ y_{H,t},\ y_{N,t},\ y_t,\ l_t,\ l_{H,t},\ l_{N,t},\ tb_t\ ,\ b_t\}$, satisfying (1.4), (1.7), (1.10), (1.12)-(1.14), (1.20)-(1.21), (1.27)-(1.30), (1.33), (1.38)-(1.43), (1.46)-(1.48) in each period, given the exogenous processes $\{g_{H,t}, y_t^*, \pi_t^*, i_t^*\}_{t=0}^{\infty}$, the government's policy rule i_t and the initial conditions τ_{-1}, $\rho_{nh,-1}$ and b_{-1}. The deterministic simulation exercise imposes the flexible price allocation on the foreign block described in (1.49)-(1.50).

1.3 Optimal Monetary Policy

In order to close the model, the equilibrium conditions have to be complemented with a description of how monetary policy is conducted. Owing to the structural features of the economy, which include both nominal and real distortions, the decisions made by the government trigger different allocations in the private sector and have a non-trivial influence on the welfare of domestic agents. Before discussing the policy problem in further detail, it is therefore a good moment to consider the sources of suboptimality in the model.

1.3.1 Sources of Suboptimality in the Model

The economic environment is characterised by three different types of distortions. To begin with, our model allows for a monopolistically competitive market structure in both the traded and nontraded sectors. As a result of this real friction, which also arises in steady state and is not offset by appropriate employment subsidies, firms enjoy some degree of market power in the goods market. Since producers are able to set their prices above marginal costs, output and employment are distorted away from their efficient level and become inefficiently low. The second source of suboptimality results from the presence of nominal inertia. As price setting decisions are subject to convex adjustment costs, any deviation of inflation from the steady state value is welfare deteriorating, as implied by the market clearing conditions (1.42) and (1.43). The last distortion of the economic environment is the so called terms of trade externality, which arises because domestic and foreign goods are imperfectly substitutable under traded sector nominal inertia. When the above assumptions are made, the monetary authority has a certain degree of market power in influencing the terms of trade in a welfare enhancing manner. The critical policy effects brought about by the external distortion will be illustrated in section 2.2.

An additional element which affects the problem facing the policy maker is with respect to whether financial markets are incomplete. This is not a typical distortion from the viewpoint of a small open economy monetary authority, as it may lead to both higher or lower levels of welfare as compared to the complete markets case. In contrast, asset market frictions are always suboptimal in two country models that analyse interdependent economies. In these alternative setups, imperfect risk sharing prevents the market allocation from being globally efficient and gives rise to cross-country demand imbalances (see Corsetti et al., 2010).

1.3.2 Optimal Monetary Policy under Full Commitment

We now turn to the main objective of our study, namely that of characterising optimal monetary policy under real convergence. In what follows, we shall explore the technical details of how the constrained efficient allocation is derived.

The Ramsey approach to optimal policy seeks to determine the allocation of resources within the economy that maximises the lifetime utility of the representative agent, while taking the private sector's expectations and equilibrium conditions as given. Entrusted with the responsibility of implementing policy is a benevolent monetary authority, who has access to a commitment technology and acts in the interest of society. Hence, the optimal plan formulated and announced in period 0 is respected even if the government might be willing to reoptimise at a later period and not honour its initial promises.[34] An important property of the Ramsey plan refers to its time-inconsistency, which is triggered by the fact that equilibrium conditions associated with the optimal policy problem are different in the initial period.

Since the government has only the interest rate instrument available, optimal monetary policy is represented by the process for $\{i_t\}_{t=0}^{\infty}$ that achieves the highest level of welfare among the set of feasible allocations, consistent with the private sector's equilibrium conditions. Following the tradition of Ramsey (1927), Lucas et al. (1983), Khan et al. (2003) and Schmitt-Grohe and Uribe (2004), agents operate in a distorted environment and there is an explicit consideration of all frictions that influence the long-run and the cyclical behaviour of economy.

From a technical point of view, the allocation problem faced by the government is formulated by setting up an infinite horizon Lagrangian:

$$\max_{\{\mathsf{y}_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t [u(\mathsf{y}_{t+1}, \mathsf{y}_t, \mathsf{y}_{t-1}, \varepsilon_t, \varepsilon_{t+1}) + \mu_t f(\mathsf{y}_{t+1}, \mathsf{y}_t, \mathsf{y}_{t-1}, \varepsilon_t, \varepsilon_{t+1})]$$

where the sans-serif symbols y_t and ε_t represent the model's endogenous and exogenous variables. The objective of the decision maker is to determine a sequence of the control variables $\{\mathsf{y}_t\}_{t=0}^{\infty}$ that maximises the discounted sum of the agent's period return functions (u). The optimisation problem is constrained, as the Ramsey plan has to satisfy the equilibrium conditions of the competitive allocation. These are represented here through the function $f(\mathsf{y}_{t+1}, \mathsf{y}_t, \mathsf{y}_{t-1}, \varepsilon_t, \varepsilon_{t+1})$, whereas μ_t denotes a vector of Lagrange multipliers.

In the context of our application, it is useful to derive a minimal set of decentralised equilibrium conditions that are relevant. This step, which reduces the number of constraints included in f, has the advantage of increasing the tractability of the Ramsey problem and leads to a more convenient set of first order conditions. In Appendix D, we show how the competitive equilibrium can be expressed in an equivalent and more compact form

[34] The distinction between the optimal plans arising under discretion and commitment is relevant even in a perfect foresight world, where the economy is subject only to an initial shock. The gains that can be obtained by deviating from the initial plan in later periods arise because of the possibility of manipulating private sector's expectations. Such incentives exist even when the future dynamics of productivity growth are fully anticipated. See Kydland and Prescott (1980) for an example.

that depends on only nine endogenous variables. Based on the alternative formulation of the constraints in equations (D.1)-(D.9), the planner's problem can be characterised as follows:

$$
\begin{aligned}
&\max_{mc_{H,t},mc_{N,t},l_{H,t},l_{N,t},c_t,\pi_{H,t},\pi_{N,t},\rho_{nh,t},\tau_t,b_t} \sum_{t=0}^{\infty} \beta^t \Bigg\{ ln(c_t) - \frac{(l_{H,t}+l_{N,t})^{1+\eta}}{1+\eta} \\
&+\mu_{1,t}\Bigg[\frac{(\frac{\pi_{H,t}}{\pi_H}-1)(\frac{\pi_{H,t}}{\pi_H})l_{H,t}}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]l_{N,t}} - \beta\frac{1+g_{H,t+1}}{1+g^*}(\frac{\pi_{H,t+1}}{\pi_{N,t+1}})\frac{(\frac{\pi_{H,t+1}}{\pi_H}-1)(\frac{\pi_{H,t+1}}{\pi_H})l_{H,t+1}}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t+1}}{\pi_N}-1)^2\big]l_{N,t+1}} \\
&\qquad - \frac{\phi\ l_{H,t}}{\psi_H\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]l_{N,t}}(mc_{H,t}-\frac{\phi-1}{\phi})\Bigg] \\
&+\mu_{2,t}\Bigg[\frac{(\frac{\pi_{N,t}}{\pi_N}-1)(\frac{\pi_{N,t}}{\pi_N})}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]} - \beta\frac{(\frac{\pi_{N,t+1}}{\pi_N}-1)(\frac{\pi_{N,t+1}}{\pi_N})}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t+1}}{\pi_N}-1)^2\big]} - \frac{\varphi}{\psi_N\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]}(mc_{N,t}-\frac{\varphi-1}{\varphi})\Bigg] \\
&+\mu_{3,t}\Bigg[\frac{1}{\Omega(.)}\frac{\tau_t}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]l_{N,t}} - \Big[\frac{1+g_{H,t+1}}{1+g^*}(\frac{\pi_{H,t+1}}{\pi_{N,t+1}})\frac{\tau_{t+1}}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t+1}}{\pi_N}-1)^2\big]l_{N,t+1}}\Big]\Bigg] \\
&+\mu_{4,t}\Big[mc_{N,t} - \frac{(l_{H,t}+l_{N,t})^\eta}{(1-\upsilon)}\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]l_{N,t}\Big] \\
&+\mu_{5,t}\Big[mc_{H,t} - \rho_{nh,t}mc_{N,t}\Big] \\
&+\mu_{6,t}\Big[\rho_{nh,t} - \Big(\frac{1+g^*}{1+g_{H,t}}\Big)\frac{\pi_{N,t}}{\pi_{H,t}}\rho_{nh,t-1}\Big] \\
&+\mu_{7,t}\Bigg[\tau_t - \frac{\big[1-\frac{\psi_H}{2}(\frac{\pi_{H,t}}{\pi_H}-1)^2\big]l_{H,t} - \frac{\theta\upsilon}{1-\upsilon}\rho_{nh,t}\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]l_{N,t}}{(1-\theta^*)y_t^*}\Bigg] \\
&+\mu_{8,t}\Bigg[c_t - \frac{1}{1-\upsilon}\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N}-1\Big)^2\Big]l_{N,t}\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)}\Bigg] \\
&+\mu_{9,t}\Bigg[b_t - \frac{\Omega(.)}{\beta}(\frac{\tau_t}{\tau_{t-1}})^{1-\upsilon+\theta\upsilon}(\frac{\rho_{nh,t-1}}{\rho_{nh,t}})^{1-\upsilon}b_{t-1} - (1+i_t^*)\Omega(.)\Big[\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}y_t - c_t\Big]\Bigg]\Bigg\}
\end{aligned}
$$

where aggregate output (y_t) is used here for notational convenience.

The government determines the optimal allocation based on first order conditions of the constrained optimisation problem, while taking the initial values of the state variables $\rho_{nh,-1}, \tau_{-1}, b_{-1}$ as given. The Ramsey system can be interpreted as a new DSGE model that is augmented with Lagrange multipliers. As shown in Appendix E, it includes the optimality conditions describing private sector's behaviour and an additional set of dynamic relationships that are obtained by differentiating the Lagrangian with respect to the choice variables $\{mc_{H,t}\}_{t=0}^{\infty}$, $\{mc_{N,t}\}_{t=0}^{\infty}$, $\{l_{H,t}\}_{t=0}^{\infty}$, $\{l_{N,t}\}_{t=0}^{\infty}$, $\{c_t\}_{t=0}^{\infty}$, $\{\pi_{H,t}\}_{t=0}^{\infty}$, $\{\pi_{N,t}\}_{t=0}^{\infty}$, $\{\rho_{nh,t}\}_{t=0}^{\infty}$, $\{\tau_t\}_{t=0}^{\infty}$, $\{b_t\}_{t=0}^{\infty}$.[35] Since both the welfare maximising allocation of domestic agents and the set of prices are determined here, it is clear that a dual approach to solving the Ramsey

[35]Notice that the set of decision variables does not include the policy instrument i_t. However, the plan for the short term interest rate can be obtained from the Euler equation, as discussed in Appendix D.

problem is adopted.[36]

In order to characterise the full commitment plan, the last technical detail that needs to be borne in mind is that the values of the Lagrange multipliers associated with the forward looking constraints have to be restricted to 0 in the initial period (as in Christiano et al., 2007; Juillard and Pelgrin, 2007). The alternative concept of optimal policy which assumes that the planner has honoured its commitments in the distant past (e.g. timeless commitment - Woodford, 2003) would be inconsistent with the nature of the real convergence phenomenon considered here. As the economy experiences a large productivity growth shock in the first period, the structure of the optimisation problem will be inherently different.

1.3.3 Simple Policy Rules

An important debate in policy circles is about what monetary policy strategy would be more aligned with the optimal response under real convergence. The norm in the Baltic states has been to anticipate euro adoption by fixing the exchange rate against the single currency, whereas countries in Central Europe have opted for more flexibility by operating under inflation targeting regimes. Yet, not much is known about the welfare performance of these alternatives and how they relate to the Ramsey plan. It is therefore informative - from a policy implementation perspective - to consider the equilibrium properties of various simple rules.

We analyse the macroeconomic implications of three alternative monetary policy regimes. The first rule imposes a reaction function that responds systematically to CPI inflation:

$$ln\Big(\frac{1+i_t}{1+i}\Big) = \alpha_\pi \; ln\Big(\frac{\pi_t}{\pi}\Big) \tag{1.51}$$

The second candidate rule studies the effects of a nominal peg:

$$ln\Big(\frac{1+i_t}{1+i}\Big) = \alpha_s \; ln\Big(\frac{S_t}{S_{t-1}}\Big) \tag{1.52}$$

Observe that international relative prices do not enter the reaction function in detrended form, such that a peg will entail the stabilisation of a composite of inflation, terms of trade and growth variables. Following the rearrangement of the terms of trade equation

[36]This contrasts the primal approach used elsewhere which requires that prices and policy instruments be expressed as a function of the allocation. However, the use of this technique is not possible in our model.

(1.31), the nominal exchange rate dynamics reads as :

$$\frac{S_t}{S_{t-1}} = \frac{1+g_{H,t}}{1+g^*} \frac{\pi_{H,t}}{\pi^*} \frac{\tau_t}{\tau_{t-1}} \tag{1.53}$$

Lastly, we also consider the equilibrium properties of a generalised Taylor rule specified below.[37] In this instance, the monetary authority adjusts the short-term instrument in response to deviations of CPI inflation from target (π) and to deviations of aggregate output from the detrended steady state value (y). Following the work of Clarida et al. (1999), we allow for the possibility of an inertial response that is consistent with interest rate smoothing.

$$\ln\left(\frac{1+i_t}{1+i}\right) = \chi \ln\left(\frac{1+i_{t-1}}{1+i}\right) + (1-\chi) \left[\alpha_\pi \ln(\frac{\pi_t}{\pi}) + \alpha_y \ln(\frac{y_t}{y})\right] \tag{1.54}$$

As we shall see in the next chapter, the choice of the monetary policy regime has important implications for the relationship between nominal and real convergence and the alignment with the Maastricht criteria.

1.4 Calibration

The model's implications for monetary policy cannot be analysed if the structural parameters are not initialised. The purpose of this section is to relate our parameter choices to previous studies that analysed the Czech Republic in the literature and to discuss how the real convergence phenomenon is modelled.

The most important element of the calibration involves the supply side adjustment driven by traded sector productivity growth (g_H). In line with the studies by Ravenna and Natalucci (2008) and Masten (2008), the real convergence scenario is designed such that it implies an excess accumulated productivity growth of 30% over a 10 year period. As a result of the restriction we impose on g_N, the dynamic process followed by g_H can likewise be interpreted as triggering a productivity differential between the traded and nontraded sectors.[38] Specifically, the first order difference equation is perturbed by a period 0 shock equal to $e_0 = 1.7\%$. Following the initial impact, traded sector productivity growth smoothly returns to g^* at a decreasing rate.[39] The adjustment of the productivity growth acceleration is governed by the autoregressive parameter ϱ, which is calibrated at 0.95.

[37] Both the inflation targeting and the Taylor rules have the feedback coefficients determined based on a numerical optimisation procedure.

[38] See equation (1.26).

[39] To determine the cumulative effect of the one-time shock, we use basic time-series methods described

Figure 1.4 reproduces the implied convergence dynamics. Notice that the effect of real convergence on the *aggregate* growth of the economy is significantly smaller, as it implies a growth acceleration of just 2 percentage points in the initial period.

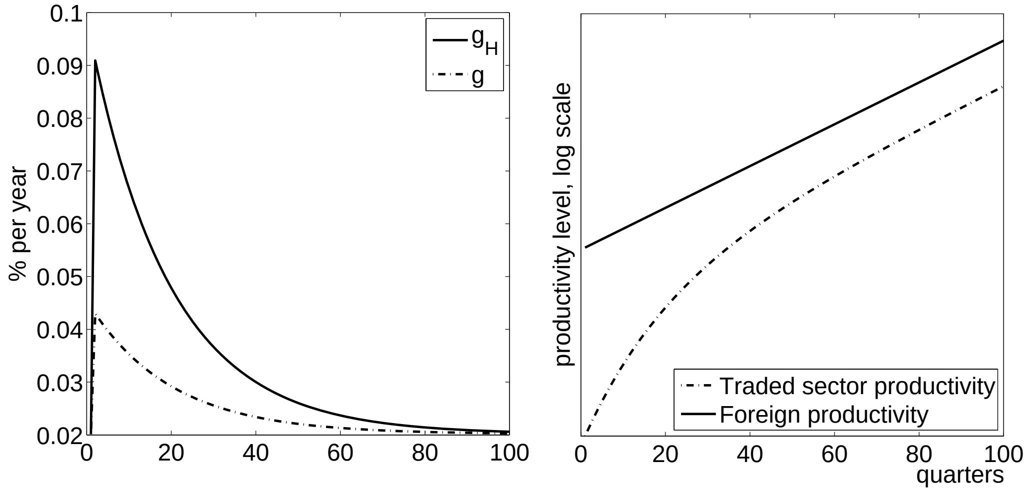


Figure 1.4: Annualised traded sector growth: convergence dynamics

The elasticities of substitution ϕ and φ are initialised based on the empirical evidence in Høj et al. (2007), Marinov (2010) and Molnar and Bottini (2008). Using the OECD-STAN database and industry-level data, Høj (2007) estimates the markups in manufacturing and services for 18 OECD economies. Even though his sample does not include the Czech Republic, the insight the above study brings is that markups in the service sector are substantially higher.[40] The evidence is robust across all countries considered. While markups in manufacturing vary in the $[0.09-0.18]$ interval, Høj (2007)'s estimated markups for the service sector range from 0.16 to 0.28.

To our knowledge, the first empirical estimates of traded sector markups in the Czech Republic are provided by Marinov (2010). Using a sample of 25,000 firms in Central Europe, the study reveals that the variable displays a large dispersion, ranging between 6% and more than 30%. However, most of the estimates are in the [0.1-0.2] interval, which is consonant with the traditional parameterisations used for the OECD and the euro area. Based on this evidence, we set $\phi = 7$.[41] The value corresponds to a 16.6% steady state

in Hamilton (1994) - Chapter 1 :

$$\sum_{s=0}^{j} \frac{dg_{H\,s}}{de_0} = \frac{1-\varrho^{j+1}}{1-\varrho}$$

[40]Including the Czech Republic in the 1975-2002 sample period would be problematic in any case, given the transition experience.

[41]Smets and Wouters (2003)'s Bayesian estimates of euro area markup range between 0.1 and 0.2.

markup and falls within the range of parameterisations chosen by other DSGE studies of the Czech Republic. Laxton and Pesenti (2003) set $\phi = 6$, while Masten (2008) chooses $\phi = 10$.

The value of φ is assigned based on the empirical evidence in Molnar and Bottini (2008), who find that markups in the Czech service industries are generally larger. Cross-sectoral heterogeneity in steady state pricing is common in the literature. Masten (2008) and Karam et al. (2008) also allow firms in the nontraded sector to have more market power. If we accept the hypothesis that transition economies display concentrated service sectors in general, an alternative justification could be provided. Consequently, we follow Bayoumi et al. (2004) and set $\varphi = 5$.

To determine the share of total consumption allocated to tradable and imported goods, we use the 2000-2007 input-output tables of the Czech Republic available in the Eurostat database and follow the common approach described in De Gregorio et al. (1994). Specifically, the output levels of tradable industries are added up and the resulting sum is divided by aggregate output at basic prices. A similar procedure is employed to compute the share of imported goods in the traded sector. As presented in table 1.1, an industry is classified as tradable if the value of its exports in total output exceeds a 10% threshold level. A curious finding is the large share of exports in the restaurants and hotels industry. Even though these services are clearly nontradables, they can be "exported" if sold to foreign residents (Lombardo and Ravenna, 2010). In light of this observation, we include the restaurants and hotels industry in the nontradable category. The allocation of industries across the two sectors is now standard. It corresponds to the classification in Stockman and Tesar (1995), where agriculture, mining, manufacturing and transport services fall in the tradables category, while all remaining services are nontradables. What can be observed from a visual inspection of table 1.2 is that the consumption shares are relatively stable over the sample period. Based on these premises, we set $\upsilon = 0.6$ and $\theta = 0.55$. To check for robustness, we estimate the shares when restaurants and hotels are included in the tradables sector. The results do not differ by more than 1 percentage point, being consistent with the rest of the literature. For example, Masten (2008) sets $\upsilon = 0.55$ and $\theta = 0.5$.

Even though not essential for the quantitative implications of the model, the rate of foreign trend growth is calibrated at $g^* = 0.5\%$. The value is consistent with a steady state growth rate of 2% a year in the euro area, which roughly corresponds to the data. Given the presence of trend growth in our model, the value of the discount factor is set at a slightly higher value than standard ($\beta = 0.9952$). Fasolo (2010) chooses a similar parameterisation in a different context. All in all, the calibration of g^* and β imply that the real interest rate equals 4% along the balanced growth path.

Table 1.1: Czech Republic - T/NT classification

Sector	Export's share of output*	Classification
Agriculture, forestry and fishing	15.86	T
Mining	24.66	T
Manufacturing		
Food, bev. and tobacco	18.69	T
Textiles	78.71	T
Wood products	32.99	T
Paper, printing and publishing	41.33	T
Chemicals	51.55	T
Nonmetalic mineral products	46.50	T
Basic metal products	50.23	T
Machinery, equipment	75.95	T
Other manufactured products	60.67	T
Services		
Wholesale and retail services	0.40	NT
Finance, insurance	6.20	NT
Transport, storage and communications	15.31	T
Real estate	0.17	NT
Government services	4.58	NT
Other services	13.67	T
Restaurants, hotels **	42.60	NT
Electricity, gas, water	5.15	NT
Constructions	0.85	NT

* at basic prices
**see the discussion in the main text

Table 1.2: Czech Republic - sectors' share

	2000	2001	2002	2003	2004	2005	2006	2007	Average
Final good									
Tradables	0.58	0.59	0.58	0.57	0.59	0.59	0.60	0.60	0.59
Nontradables	0.42	0.41	0.42	0.43	0.41	0.41	0.40	0.40	0.41
Tradable good									
Imports	0.45	0.44	0.42	0.43	0.46	0.45	0.46	0.46	0.45

The price stickiness parameters are set at $\psi_H = 60$ and $\psi_N = 40$, which are close to the value of 50 used in Bergin et al. (2007). The cross-sector variation is justified based on and the Czech NKPC estimates and the heterogeneity in markups assumed earlier. In Mihailov

Table 1.3: Calibrated parameters

Parameter	symbol	value
Discount factor	β	0.9952
Long run growth rate	g^*	0.005
Persistence of the productivity growth process	ϱ	0.95
Share of traded goods in final consumption	υ	0.6
Share of domestic goods in tradable consumption	θ	0.55
Share of foreign goods in foreign consumption	θ^*	0.67
Elasticity of substitution among intermediate goods - T	ϕ	7
Elasticity of substitution among intermediate goods - NT	φ	5
Degree of price stickiness in the traded sector	ψ_H	60
Degree of price stickiness in the nontraded sector	ψ_N	40
Inverse elasticity of labour supply	η	1
Elasticity of the risk premium with respect to b	ξ	0.01
Traded sector rate of inflation	π_H	$1.02^{\frac{1}{4}}$
Nontraded sector rate of inflation	π_N	$1.02^{\frac{1}{4}}$
Initial net foreign assets position	b	0
Steady state net foreign assets position	$\bar{b}$	0

et al. (2011), the estimated coefficient of the real marginal cost lies in the [0.09-0.13] interval, contingent on the specification. When nominal rigidities are introduced using the Rotemberg apparatus, the theoretical mapping of the real marginal cost coefficient corresponds to $\varsigma = \frac{\phi-1}{\psi}$.[42] Our parameterisation implies that $\varsigma = 0.1$. Given the chosen elasticities of substitution, the values of ψ_H and ψ_N are arrived at immediately.[43] Taking into account the equivalence between the Rotemberg and Calvo models up to a first order approximation, it is useful to infer the average time interval in which firms adjust their prices. To do so, we use the NKPC in Mattesini and Nisticò (2010, eq. (45)), derived in the presence of trend growth:

$$\pi_t = \beta\gamma^{1-\sigma} E_t \pi_{t+1} + \varsigma mc_t, \qquad \text{with } \varsigma = \frac{(1-\alpha)(1-\alpha\beta\gamma^{1-\sigma})}{\alpha} \tag{1.55}$$

In (1.55), γ represents trend growth, being equivalent to $1+g$, σ is the CRRA coefficient equal to 1 in our case, while $1-\alpha$ denotes the probability of receiving a random price signal to reoptimise.

Note that when the elasticity of intertemporal substitution is equal to 1, the NKPC has the usual canonical representation. Our calibration implies that the average duration of a price contract is of 11 months and that the fraction of reoptimising firms equals 0.27.

[42]See Lombardo and Vestin (2008) for a derivation.
[43]$\psi = \frac{\phi-1}{\varsigma}$.

We choose the sensitivity of the external borrowing cost to bond adjustment, ξ, based on the empirical evidence in Lane and Milesi-Ferretti (2001). The authors test the relationship between real interest rate differentials and the ratio of net foreign assets to exports and conclude that a 20 percentage point improvement in the latter is associated with a 50 basis points reduction in the former.[44] In terms of the UIP condition we derived in (1.33), the implied value of ξ would be 0.025. Since b represents the ratio of net foreign assets to output in our model, we set the sensitivity parameter at a slightly lower value ($\xi = 0.01$). Justiniano and Preston (2010a) and Benigno (2009) adopt a similar calibration.

Lastly, the presence of incomplete asset markets requires a parameterisation of the initial level of the net foreign assets position b_t and its steady state value $\bar{b}$, which are both set at 0. These values roughly correspond to the 1996-2000 empirical averages of the variable, computed in Lane and Milesi-Ferretti (2007). The reason we choose data averages instead of particular realisations is because the dynamic system is assumed to be in a pre-convergence equilibrium. While the assumption is to a certain extent arbitrary, it has the advantage that it permits an analytical solution to the steady state system. Its characterisation is done in appendix F, where all the steps involved in the derivation are explained.

[44] Op. cit. table 7, panel (b).

Chapter 2

Optimal Monetary Policy under Real Convergence

This chapter addresses the question of how monetary policy should be conducted under real convergence, using as a reference framework the model developed in Chapter 1. In terms of its objectives, the present work provides a detailed characterisation of the Ramsey plan and discusses the optimal interest rate adjustment in relation to the various externalities in the model. Chapter 2 also conducts a welfare-based evaluation of simple rules, while showing how the equilibrium allocations under inflation targeting and fixed exchange rate policies relate to the optimal plan. The analysis is aimed not only at emphasising what monetary policy strategy is appropriate under real convergence, but also at indicating whether the conditional transition paths are compatible with the Maastricht criteria. The policy experiments are conducted in two alternative market structures, represented by monopolistic competition (sections 2.1-2.4) and perfect competition (section 2.5) in the traded sector. Lastly, the final part considers the evaluation of the Maastricht constrained optimal plan. The equilibrium allocations conditional on the monetary policy regime in place are determined numerically, by simulating the fully nonlinear model in Dynare using several Newton-based algorithms.[1]

The presentation of the results is organised as follows. The first section discusses the convergence dynamics under flexible prices. This simplified version of the model will prove a useful reference for understanding the more sophisticated tradeoffs and incentives guiding the full-commitment optimal plan. A closely related point concerns the model's ability to generate sensible implications for structural change. In section 2.2 we analyse the equilibrium properties of the endogenous variables under the Ramsey plan. Section 2.3 discusses optimised simple rules of the type considered in equation (1.54). As the number of parameters that need to be optimised is high, we limit our search to three dimensions across the parameter space, by ignoring the response to nominal exchange rate movements.[2] The discussion proceeds with a comparative examination of a strict inflation targeting rule and of a nominal peg. Section 2.4 assesses the sensitivity of the results with respect to the degree of price inertia and with respect to the persistence of the convergence shock. Section 2.5 shows how the policy implications are changed when

[1] Sparse-LU, Relaxation Method, Optimpath. All the numerical routines generated identical transition paths.

[2] The Nelder-Mead algorithm of searching the parameter space might not be reliable when the number of optimised parameters is high - see Lagarias et al. (1998).

perfect competition in the traded sector is assumed. Section 2.6 discusses the Maastricht constrained optimal plan. Section 2.7 concludes.

2.1 Dynamics under Flexible Prices

We begin by examining the natural-rate allocation, which corresponds to the decentralised equilibrium when all prices are flexible. In the absence of nominal inertia in the two sectors ($\psi_H = \psi_N = 0$), firms choose their production levels at the point where the sector specific real marginal costs are constant. Interestingly enough, all the rescaled relative prices and quantities appearing in Appendix B inherit the same property. A proof of this result is similar to the derivation of the nonstochastic steady state in Appendix F.

The absence of a strong wealth effect that would otherwise cause excess deviations of the natural level of consumption away from the nonstationary productivity trend is a direct consequence of the preference structure we adopted. Given the unitary values of the intertemporal and cross-goods elasticities of substitution, it is clear that the income and substitution effects shaping the intertemporal consumption profile exactly offset each other when the above assumptions are made. This line of reasoning also applies to the interpretation of the sticky price allocations, where the presence of nominal inertia does not trigger significant deviations of real variables away from the corresponding productivity trends.

By imposing a unitary elasticity of intertemporal substitution in consumption ($\frac{1}{\sigma} = 1$), our utility function is identical to the one adopted in the simple NK framework of Galı et al. (2003). Similarly to the present study, the theoretical experiments conducted by Galı et al. (2003) in their one sector closed economy model are concerned with the policy implications of temporary shifts in the growth rate of total factor productivity. By assuming the existence of appropriate fiscal instruments to correct the distortions induced by monopolistic competition, Galı et al. (2003) focus on the optimal implementation of monetary policy when staggered price adjustment is the only friction that needs to be remedied. Not surprisingly, the study finds that a policy that replicates the flexible price allocation can be implemented by achieving domestic price stability. Similarly to the standard case of stationary productivity shocks, the above policy also succeeds in closing the output gap, measured in terms of deviations from the nonstationary natural-rate allocation. An essential idea that can be assimilated from the Galı et al. (2003) model is that, when preferences are additive in consumption and disutility of effort, the inverse elasticity of intertemporal substitution σ has an impact of the time-series properties of employment.

For example, the variable is stationary only when $\sigma = 1$, whereas aggregate employment moves proportionally to the nonstationary productivity trend for higher values of the σ parameter.

In consideration of the above effect, we have made several assumptions which ensure that the natural rate of aggregate employment is not only bounded, but also constant. However, the presence of multiple goods that are imperfectly substitutable may give rise to structural change, which entails a reallocation of the labour inputs from one sector to the other. Thus, even if the King et al. (1988) preference structure results in a constant natural level of aggregate employment, the model could still imply that the time spent working in one sector, as a fraction of l, changes during a real convergence episode. Nonetheless and similarly to the recent two-country model developed by Liu and Pappa (2008), which focuses on the gains from international monetary policy cooperation, the natural levels of employment in each sector are completely insulated from the convergence shock. Hence, under flexible prices, the economy responds to the increased supply of traded goods mainly through movements in relative prices.[3] The reader might already be curious about the assumptions that lead to the absence of structural change in our model. Before addressing this question in more detail, it is a right moment to derive some expressions describing the natural-rate allocation. These will prove very useful later on when the Ramsey transition paths are explained.

In unnormalised form, the natural rates of the sector-specific levels of employment, consumption and output are given by:

$$l^n_{H,t} = l_H \tag{2.1}$$

$$l^n_{N,t} = l_N \tag{2.2}$$

$$ln\ C^n_{H,t} = ln\ c_H + ln\ \Gamma_{H,t} \tag{2.3}$$

$$ln\ C^n_{N,t} = ln\ c_N + ln\ \Gamma_{N,t} \tag{2.4}$$

$$ln\ Y^n_{H,t} = ln\ y_H + ln\ \Gamma_{H,t} \tag{2.5}$$

$$ln\ Y^n_{N,t} = ln\ y_N + ln\ \Gamma_{N,t} \tag{2.6}$$

where expressions without a time subscript correspond to steady state detrended variables.[4]

In their classical contribution, Clarida et al. (1999, p.1674-1675) have mentioned that "a

[3] In addition to the two-country environment and the complete markets setting, the main difference between the framework in Liu and Pappa (2008) and ours is that, in their case, productivity growth rates in each sector follow a potentially correlated random walk.

[4] See Appendix F.

permanent rise in productivity raises potential output, but it also raises output demand in a perfectly offsetting manner, due to the impact on permanent income." It is clear that the principle formulated by them regarding the optimal policy accommodation of shocks to potential output also applies here. This effect occurs because the natural levels of output and consumption move together, being proportional to the relevant trend variable Γ. Due to the automatic adjustment in demand, Clarida et al. (1999) went on to argue that monetary policy with respect to changes in potential output should be passive, as there is no excess demand and therefore no change in inflation.[5] In contrast to the view expressed above, a clear message from this chapter is that movements in the *growth rate of potential output* may require an *active, countercyclical* policy response. An easy way to see this is by determining the natural real interest rate in our economy:

$$1 + r_t^n = E_t\Big[\frac{1 + g_{t+1}}{\beta}\Big] \tag{2.7}$$

As r_t^n moves proportionally to the expected aggregate growth rate, it follows that the adjustment of the natural real interest rate is countercyclical.

Based on the steady state results and given the transformations in Appendix B, we can express the natural rates for a set of relative prices as:

$$T_t^n = \frac{(1-\theta)Y_{H,t}^n}{(1-\theta^*)Y_t^*} \tag{2.8}$$

$$ln\ T_t^n = ln\ \tau + ln\ \Gamma_{H,t} - ln\ \Gamma_t^* \tag{2.9}$$

$$ln\ R_{NH,t}^n = ln\ \rho_{nh} + ln\ \Gamma_{H,t} - ln\ \Gamma_{N,t} \tag{2.10}$$

$$ln\ Q_t^n = ln\ q + ln\ \Gamma_t - \Gamma_t^* \tag{2.11}$$

The alternative representations of the natural terms of trade simply state that a real convergence episode, in which domestic traded sector output grows at a higher rate as compared to the foreign economy, has to be accompanied by a proportionate change in relative prices. Hence, via this external expenditure switching mechanism, the higher level of T_t^n implied by these relationships means that home terms of trade will deteriorate. Moreover, equation (2.8) suggests that a policy maker can engineer an improvement in the international competitiveness of domestic products, relative to the natural rate allocation, by reducing the number of traded sector hours supplied to the market. A contractionary monetary policy can be used for this purpose.

[5] In more general setups, the degree of validity of the above principle crucially depends on the efficiency of the flexible price allocation and on the ability of the policy maker to replicate its outcome. We will discuss this in detail in the next section.

An identical principle applies to the internal expenditure switching mechanism, which requires a higher nontraded inflation rate. Observe that, because the natural levels of employment are constant, all the adjustment to the increased supply of traded goods occurs through changes in relative prices.

Finally, the natural real exchange rate depends positively on terms of trade and negatively on the relative price of nontraded goods.[6] Equation (2.11) indicates that the depreciating terms of trade effects will dominate. Note that the increase in Q_t^n is more muted, as it depends on the aggregate trend Γ_t, which increases at a lower rate as compared to $\Gamma_{H,t}$.

2.1.1 Understanding the Absence of Structural Change in the Flexible Price Allocation

Why does a persistent, higher productivity growth in the traded goods sector not lead to a different long-run allocation of the labour input across sectors (e.g. structural change)?

The relationship between the allocation of employment in the economy and unbalanced growth has been extensively studied in the literature.[7,8] A recent study of the goods-services productivity dichotomy is offered by Ngai and Pissarides (2007), who ask whether a macroeconomic model can account for both the Kaldor facts regarding economic growth and the possibility of ongoing structural change towards the nontraded sector.[9] By choosing a CES specification of the final consumption aggregator, Ngai and Pissarides (2007) show that an elasticity of substitution below 1 leads to a relative increase of employment in sectors with low total factor productivity growth. Moreover, "in sectors producing only

[6] See equation (1.40).

[7] The general interest in the topic has been stimulated by the ever increasing service sector share of aggregate employment and its effects on the long-run growth prospects of developed countries. Recent evidence reveals that the service sector accounts for about 70% of aggregate employment in almost all OECD economies and continues to grow (Kongsamut et al., 1997; Wölfl, 2005). Fuchs (1968) associates the structural shift of employment towards the service sector to three factors: a higher elasticity of demand for services, a higher productivity growth in manufacturing and the potential for service firms to become centres of outsourcing activities.

[8] Baumöl (1967) is the first contribution that models the relationship between structural change and asymmetric productivity developments. By distinguishing between technologically progressive and non-progressive activities which use labour as the only input in production, the author argues that unbalanced growth induces a resource reallocation towards the service sector. The eventual flow of employment into unproductive activities causes an indefinite rise in the production costs and a reduction of aggregate economic growth. This unattractive feature of real economies has been named afterwards as "Baumol's cost disease" - see Maroto and Rubalcaba (2008) for an extensive discussion.

[9] Their closed economy model comprises of m sectors differentiated by the rate of productivity growth. While all goods are produced using capital and labour, which are freely mobile across the economy, the production of the manufacturing good is the only one that can be used for both capital accumulation and consumption purposes. This enables the authors to study the effects of structural change even when the employment shares of some high productivity goods falls to zero.

consumption goods, relative employment shares grow in proportion to relative prices, with the factor of proportionality given by one minus the elasticity of substitution between goods " (Ngai and Pissarides, 2007).

In appendix G, we derive an identical result within our model. To do so, we simplify the structure of the theoretical environment by looking, without loss of generality, at a two-sector closed economy specification. As the question to be answered concerns the long-run implications of structural change for the relative allocation of hours across sectors, we restrict our attention to the decentralised allocation that results under flexible prices. The above modifications allow us to generalise the functional form defining preferences, to introduce a CES specification of aggregate consumption and to also relax the assumption of perfect labour mobility. The main result that emerges is that relative hours grow in inverse proportion to the relative productivity growth rates, with the factor of proportionality being influenced by the elasticity of substitution between the two goods, and the degree of labour mobility in the economy. Moreover, as in Ngai and Pissarides (2007), a unitary elasticity of substitution is consistent with the absence of structural change. Hence, the constant values of the natural rates of employment observed in figure 2.2b are the result of the Cobb-Douglas functional form adopted in defining the aggregate consumption index.

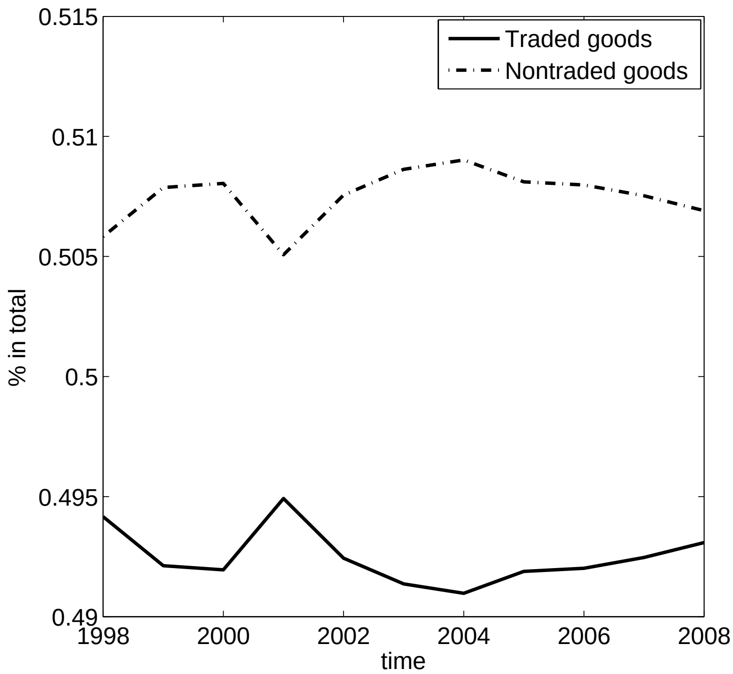


Figure 2.1: Czech Republic - total hours per worker in the traded and nontraded sectors

Even though per capita income growth has generally been accompanied by a shift in employment shares towards the service sector among other OECD economies, the recent experience of the Czech Republic has witnessed quite stable labour market patterns. This effect is depicted in figure 2.1, where we compute the recent empirical values of total sector-specific hours per worker, expressed in relative proportion. Thus, the absence of significant structural change is consistent with the stylised facts observed in the data. As we shall see, the presence of nominal rigidities in the two sectors will allow for optimal, transitory fluctuations of hours.

2.2 Dynamics under Optimal Policy

Traditional studies of monetary policy (e.g. Clarida et al., 1999; Khan et al., 2003) have long emphasised the conditions under which domestic price stability is optimal in closed economies. The general prescription of these workhorse models for policy analysis is that transitory supply side adjustments should be accommodated through activist monetary interventions. Intuitively, the incidence of a positive technology shock gives rise to a gap between the actual and the potential levels of output. In the presence of price stickiness, where production is demand-determined, a policy that stimulates aggregate demand by lowering nominal interest rates is able to move output closer to its efficient level. Such a response is thus welfare improving. To the extent that the policy problem is only concerned about correcting the inefficiencies caused by nominal inertia, replicating the flexible price allocation is not only optimal, but can be achieved through a policy of domestic price stability. The difference between the models in Clarida et al. (1999) and Khan et al. (2003) is given by the extent to which the real distortion implied by the market power that firms enjoy under monopolistic competition is corrected through adequate employment subsidies. If this is the case, as in the former paper, the flexible price allocation is also efficient. On the other hand, Khan et al. (2003) allow for an inefficiently low level of output and employment, even in steady state. For this reason, greater welfare gains can be achieved relative to the natural rate allocation by inflating the economy in the short-run. This enables the policy maker to move output and employment even closer to their efficient levels.[10]

The story is slightly different when transitory shocks to the growth rate of potential output are taken into account. If the steady state is efficient, as in Galı et al. (2003), implementing the flexible price allocation is still optimal and also corresponds to domestic price stability. Moreover, optimal policy is represented by an instrument response that is proportional to movements in the natural rate of interest. The key difference between the

[10]See Galí (2008), chapter 5, for a textbook exposition.

case of stationary technology shocks explained above and the one of transitory movements in the productivity growth rate, which is relevant to our framework, is that the natural rate of interest *increases*. This effect can be clearly observed from equation (2.7), where we have shown that r_t^n is proportional to the aggregate growth rate g_{t+1}.

In their basic one sector closed economy model, Galı et al. (2003) show that equilibrium dynamics of the nominal interest rate under optimal policy is represented by:

$$i_t = (1 - \varrho)\; i + \varrho\; i_{t-1} + \sigma \varrho\; \Xi\; e_0 \tag{2.12}$$

We have adapted the notation of the original paper to correspond to the one used here. ϱ corresponds to the persistence parameter in (1.24), i defines the steady state level of nominal interest rates, σ is the risk aversion parameter, while the parameter Ξ is defined as $\Xi = \frac{1+\eta}{\sigma+\eta}$. Previously defined on page 50, e_0 corresponds to the initial convergence shock. Notice that, consistent with the calibration adopted by Galı et al. (2003), σ and Ξ have a unitary value.

Hence, one can expect that if the optimal policy response in the closed economy is isomorphic to a two-sector small open economy model, then the path followed by the policy instrument should have a smoothing behaviour that gradually returns towards steady state following an initial countercyclical response.

There are, however, five essential differences between the Galı et al. (2003) model and the present study. First, we allow for asymmetric movements of productivity growth rates in the traded and nontraded sectors. In addition, if nominal rigidities are present throughout the economy, then replicating the flexible price allocation is not possible. As a result, the optimal policy problem involves tradeoffs between stabilising inflation and output deviations from their efficient levels in the two sectors. The third distinction that needs to be taken into account is that in our model the steady state is distorted in both sectors. As we mentioned before, this type of real inefficiency creates incentives to inflate the economy relative to the natural rate allocation. Importantly, the open economy dimension of our model has nontrivial consequences for the optimal policy design, as it creates additional deflationary incentives that arise as a result of an external distortion. Due to the last two externalities, which are not offset through appropriate fiscal instruments, the flexible price allocation is not Pareto optimal in our model. In fact, by engineering appropriate relative price changes, the Ramsey planner can improve upon the flexible price allocation even when nominal price adjustment is costly. Finally, as the magnitude of the initial shock e_0 is large, the use of local approximation techniques for determining the optimal responses is inappropriate. We discuss the implications of all these differences below.

Subsequent research has further developed the canonical New-Keynesian model, by extending the normative implications for monetary policy to multi-sector environments. For example, Aoki (2001) found that if nominal adjustment is imperfect in one sector only, then the price stability objective can be extended if it is applied to the core component of aggregate inflation. On the other hand, the recent contributions by Canzoneri et al. (2005) and Liu and Pappa (2008) proved that the presence of nominal rigidities in both the traded and nontraded sectors of an open economy makes the implementation of the flexible price allocation infeasible, except for very special cases.[11] In this respect, Liu and Pappa (2008) identified three situations when the natural rate allocation can be achieved: (i) the model collapses to a one sector economy; (ii) there is only one source of nominal rigidity, as in Aoki (2001); (iii) productivity shocks are perfectly correlated. It is clear that none of the above conditions is met in our case. Intuitively, the flexible price allocation cannot be implemented due to an instrument insufficiency problem (Canzoneri et al., 2005). Since productivity growth adjustments are asymmetric, the policy response would have to accommodate two different sources of technological trend variation, even if it only has the nominal interest rate instrument available. As a result, the optimal plan depends on measures of output and inflation volatility in the two sectors, thereby triggering sectoral tradeoffs.

The two-country model of Liu and Pappa (2008) is also the first one to elucidate the appropriate subsidy scheme that ensures the optimality of the natural rate allocation in a two-sector environment. Derived within a complete markets setting, their results show that the flexible price allocation is efficient if the traded sector production subsidy depends not only on the steady state markup, but also on the share of domestic goods in the traded consumption index. In fact, this requirement is identical to the one sector results in Gali and Monacelli (2005) and De Paoli (2009a). The novel finding, however, is that the nontraded sector subsidy exactly offsets the steady state markup distortion in that sector, being consistent with standard closed economy results.[12] An open economy monetary policy analysis cannot be properly understood without addressing the incentives that trigger a different government intervention in the two sectors. It is therefore a good moment to discuss the additional layer of complexity in the optimal policy problem conveyed by moving from a closed economy to an open economy environment.

The critical difference the existence of international trade brings is that domestic agents consume an additional imported good, which directly affects their welfare. When home and foreign goods are imperfectly substitutable and prices are sticky, the monetary au-

[11] See Proposition 1 and the discussion in Liu and Pappa (2008, p.2097-2100).

[12] Leith and Wren-Lewis (2007) derive a similar result in the context of a small open economy model.

thority enjoys a certain degree of market power in influencing the terms of trade.[13] As it has been emphasised by Corsetti and Pesenti (2001), this externality can lead to unorthodox policy implications. To give just a flavour of the complications that arise, imagine that the open economy comprises only one sector that it is perturbed by positive, stationary productivity shocks. We saw in the beginning of this section how an expansionary monetary policy is always welfare improving in a closed economy environment. However, when trade in international goods is possible, there are additional channels that may have nontrivial effects on the policy problem. In an open economy environment, stimulating aggregate demand by lowering nominal interest rates also leads to a terms of trade deterioration which increases the domestic price of foreign goods. Since the latter also influences the aggregate price index, domestic agents suffer a reduction in their purchasing power, that adversely affects the real wage for a given level of hours worked. This wealth effect, in turn, induces consumers to either work more or consume less of the aggregate good, resulting in a welfare deterioration. Hence, the open economy policy problem becomes more complicated because correcting aggregate demand externalities through an expansionary monetary policy might not be optimal (see Corsetti and Pesenti, 2001).

Due to the transmission channel outlined above, it becomes clear that the policy maker has an incentive to implement a contractionary monetary policy in an open economy environment. A deflationary policy that appreciates the terms of trade enables residents to switch from the consumption of domestic to foreign goods. This expenditure switching effect, in turn, leads to a decrease in home production levels. Even though aggregate consumption might be lower, "the reduction in utility that comes from the decrease in consumption could potentially be more than offset by the reduction in the disutility of producing goods" (Benigno and Benigno, 2003). To sum things up, a contractionary monetary policy may be welfare improving in open economy environments, as the Ramsey planner can make effective use of terms of trade externality to manipulate the relative price of domestic goods in her favour.[14]

Under special restrictions on the structural parameters, complete markets studies such as Gali and Monacelli (2005) or Liu and Pappa (2008) managed to derive the subsidies necessary to offset the combined effects of the internal and external distortions, focusing only on the welfare costs generated by nominal inertia. It is precisely in such circumstances when the optimal policy problem can be isomorphic to the one in a closed economy model,

[13] When prices are flexible, the terms of trade externality does not exist and the policy maker cannot improve upon the welfare outcome of the flexible price allocation. There is no scope for monetary policy in this case.

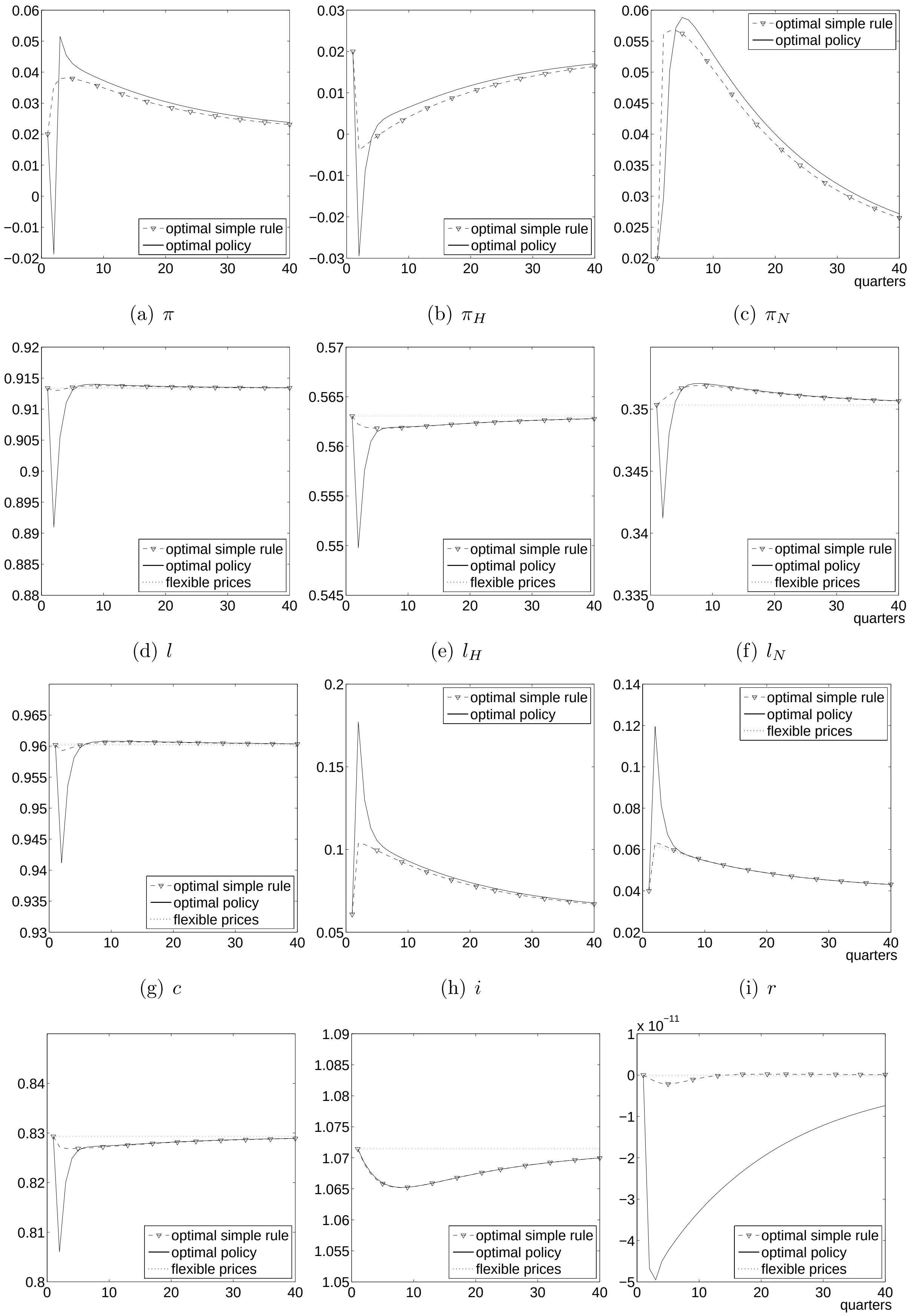
[14] The terms of trade externality has been documented in many places: e.g. Corsetti and Pesenti (2001, 2005), Benigno and Benigno (2003), Faia and Monacelli (2008), Liu and Pappa (2008), De Paoli (2009a) or Rabitsch (2012).

mainly because the flexible price allocation is optimal. Whereas the one sector model of Gali and Monacelli (2005) has only one source of inefficiency due to imperfect nominal adjustment, the framework by Liu and Pappa (2008) is characterised by nominal rigidities in both sectors of the economy. In both studies, the flexible price allocation is Pareto optimal. However, the presence of a different number of externalities implies that the natural rate allocation can only be implemented in the Gali and Monacelli (2005) model.

Because of the applied nature of our study, we refrain from making the unrealistic assumption that the distortions caused by market power have been corrected through appropriate employment subsidies. Moreover, as we have mentioned before, the assumption of financial trade in noncontingent bonds makes the computation of the first best allocation intractable. For these reasons, it is understood that the constrained efficient plan in figures 2.2a and 2.2b should be interpreted based on the various externalities the Ramsey planner trades off when undertaking policy under commitment. In fact, our conditional welfare results are in line with the argument in Faia and Monacelli (2008), who signalled that "in the (constrained) efficient allocation of an open economy, (...) the planner can improve upon the constant-markup allocation prevailing under flexible prices." This is despite the fact that the natural rate allocation cannot be implemented. Lastly, the fully nonlinear solution method brings important insights on how the monetary authority trades off the internal and external distortions in setting up the constrained efficient allocation, when transitory shifts in traded sector productivity growth have a large magnitude. Such experiments have not been conducted before in the literature.

Now that we have provided the reader with an extensive background, we address the interpretation of the Ramsey transition paths. Figures 2.2a and 2.2b depict the short-run and the long-run responses of the detrended system under the natural rate allocation, the Ramsey plan and the optimal simple rule. Annualised net values are used to display the transition paths of inflation and interest rates. The numerical solution reveals that, by raising real interest rates substantially above their natural levels for a two-year period, the social planner engineers a short-term contraction in demand relative to the flexible price allocation. Her policy actions lead to a persistent disinflation process amongst traded goods and a reduction in labour effort. In figure 2.3, we show that the countercyclical policy response also induces a short-lived terms of trade and real exchange rate appreciation with respect to their long-run depreciating trends.[15] In our model, the gains from the extra purchasing power that domestic residents enjoy in international markets allow households to purchase relatively more foreign goods and to reduce home production.

[15]See the expressions in (2.9) and (2.11).



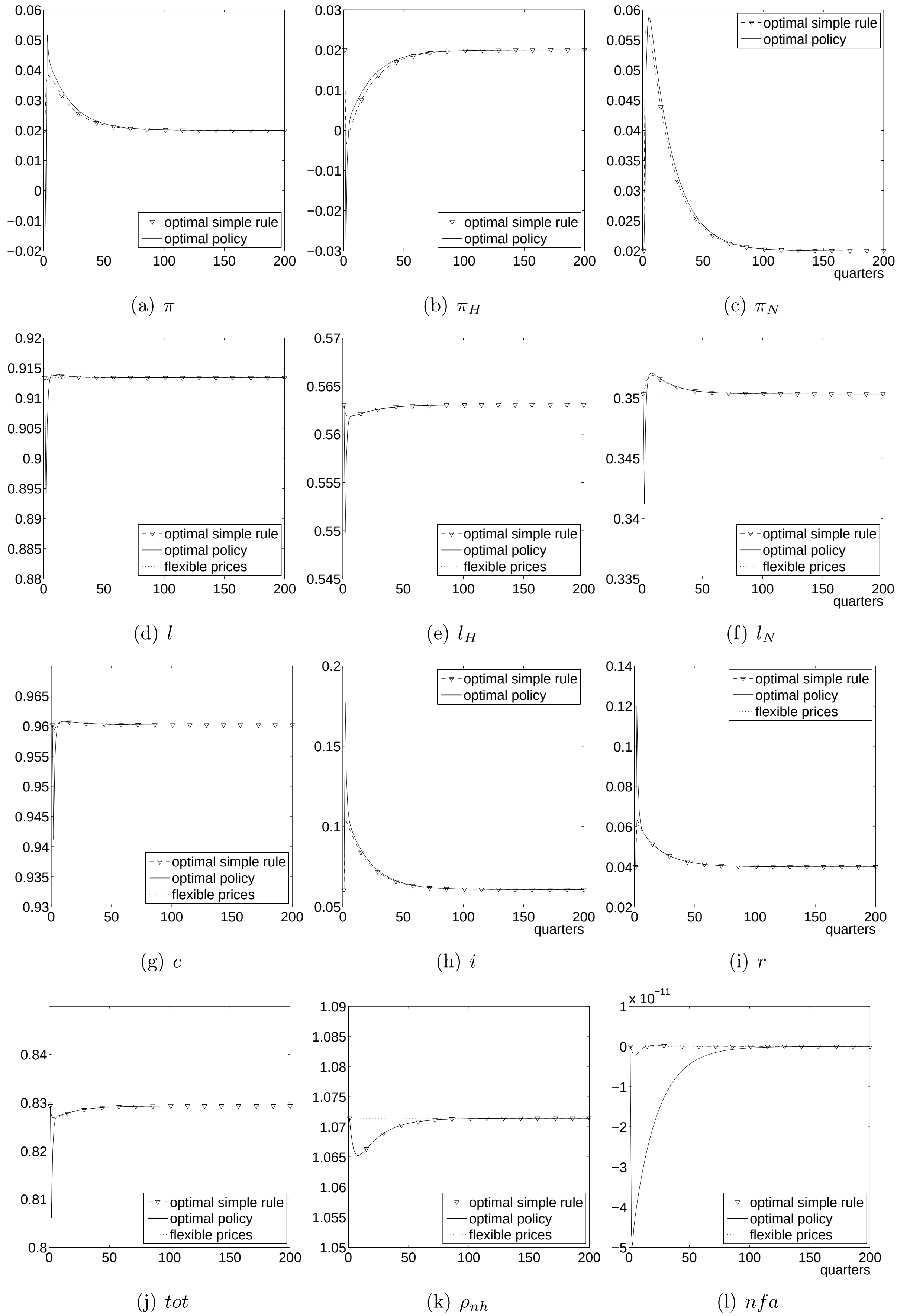
(a) π (b) π_H (c) π_N

(d) l (e) l_H (f) l_N

(g) c (h) i (i) r

(j) tot (k) ρ_{nh} (l) nfa

Figure 2.2a: Convergence shock - short-run responses



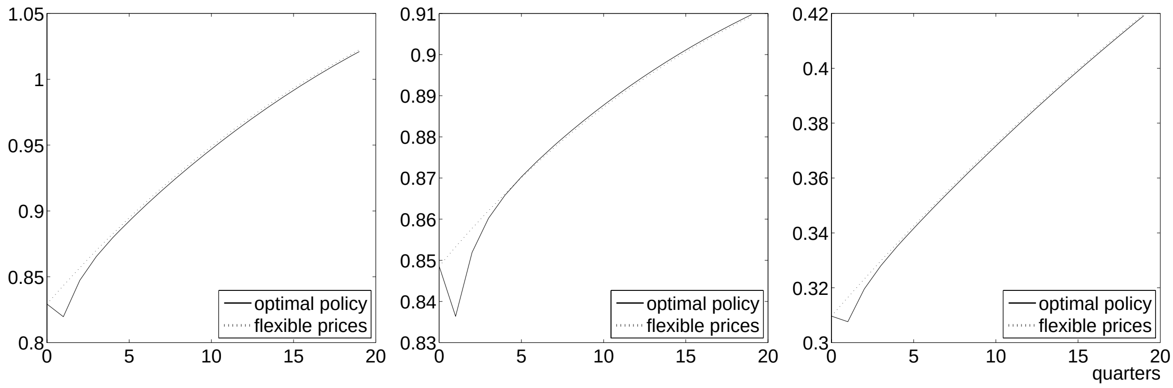
(a) π (b) π_H (c) π_N

(d) l (e) l_H (f) l_N

(g) c (h) i (i) r

(j) tot (k) ρ_{nh} (l) nfa

Figure 2.2b: Convergence shock - long-run responses



(a) T_t (b) Q_t (c) $C_{H,t}$

Figure 2.3: The effects of the terms of trade externality on the Ramsey plan

The expenditure switching effect is presented in the third panel, where we show that $C_{H,t}$ falls relative to the natural level. Owing to imperfect risk sharing, domestic consumption and production move closely together, such that domestic agents cannot improve their utility by working less without reducing their consumption levels (see De Paoli, 2009b, p.1303). Since the increase in purchasing power has a positive wealth effect, these agents are made better off even though their aggregate consumption falls. Under the optimal plan, the reduction in the disutility of effort exceeds the utility loss created by a lower aggregate consumption level.[16] For these reasons, we can confidently infer that the incentive to manipulate the terms of trade is dominant.

The reason why optimal monetary policy is mainly influenced by the terms of trade externality, and less by the incentive to correct aggregate demand distortions, is easy to elucidate. In this sense, Corsetti and Pesenti (2001, p.423) notice that "small and more open economies are more likely to suffer from domestic nominal shocks that worsen their terms of trade." By reversing their argument, it follows that the welfare gains brought about by lower relative prices are large when the share of imported goods in the domestic tradable basket is high.[17] To understand this point, the reader is referred to the derivation of the optimal subsidy in Gali and Monacelli (2005, p.720), who showed that the fiscal intervention is increasing in the consumption share of imported goods. Intuitively, the larger $(1-\theta)$ is, the more potential there is for the substitution effect to work in the benefit of domestic agents. Although we impose a unitary trade elasticity of substitution, a similar line of reasoning can be applied to understand why the incentive to manipulate

[16]A visual inspection of panels (d) and (g) of figure 2.2a illustrates this point. Both endogenous components of domestic welfare, l and c fall in the initial period by approximately 0.02. Whereas consumption enters the lifetime utility function in logs, the disutility of effort is quadratic, as $\eta = 1$.

[17]In our case, $1-\theta$ equals 0.45.

the terms of trade is stronger when domestic and foreign goods are less differentiated.[18] Finally, as the degree of market power the policy maker enjoys in setting up the terms of trade is higher when traded sector prices are stickier, one can expect that more nominal inertia will increase the welfare losses of the simple policy rules relative to the Ramsey plan. This effect is confirmed in our sensitivity analysis.[19]

The strong countercyclical policy response to the real convergence shock encompasses both the increase in the natural rate of interest and the incentive to deflate the economy even more, caused by the external distortion. In consideration of the steady state inefficiencies underlying our model, it is natural to ask how much of the optimal interest rate response is truly attributable to the real convergence phenomenon, as opposed to the scope for engineering a short-term policy contraction even in the absence of shocks. Finding that our results are mostly dominated by the structural features of the model would be problematic, as the ensuing policy prescriptions would not be as reliable as otherwise. Figure 2.4 addresses the above question by comparing the baseline allocation to the optimal plan that would result in the absence of shocks. It becomes clear that the terms of trade externality has a noteworthy influence only in first period, where it accounts for more than half of the countercyclical response. However, the influence of the steady state distortions on the optimal allocation is attenuated soon after and by no means has a significant contribution on the medium and long-term dynamics. Despite this, one can imagine that the terms of trade externality would clearly have a much more compelling influence if the policy maker operated under discretion. Indeed, it goes without saying that a central bank would raise nominal interest rates period by period in that case.

In terms of quantitative predictions, the annualised value of the initial nominal interest rate response is 17.5% and only reaches the long-term steady state after 25 years. On the other hand, the real interest rate response is still significant, although positive deviations with respect to the natural rate can only be observed during the first five quarters. The transition path of the variable suggests that the welfare gains the Ramsey plan can achieve are only possible in the short-run. External constraints caused by the UIP condition prevent the social planner from engineering more persistent terms of trade improvements. In fact, the detrended levels of the relative prices τ_t and q_t reach their lowest point after just one period.[20] Notice that rescaled aggregate consumption also changes its dynamics and switches its sign by moving towards the steady state. This effect is consistent with the incomplete markets result which states that the growth rate of the relative consumption

[18] The analysis of De Paoli (2009b) illustrates why optimal monetary policy in a small open economy depends on the trade elasticity of substitution and the degree of international risk sharing.

[19] See section 2.4.

[20] The graph for q_t is not reported due to space limitations, but it is understood that the real exchange rate displays a similar transition path, as it is proportional to the terms of trade.

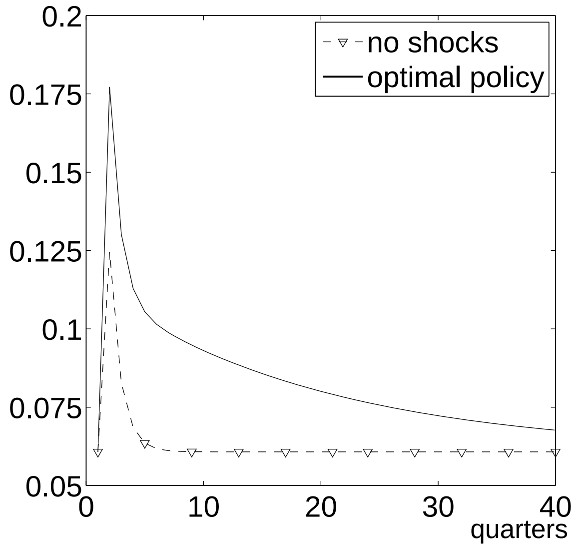


Figure 2.4: Decomposing the optimal interest rate response. Effects of the real convergence shock.

differential is proportional to the rate of real exchange rate depreciation (see Chari et al., 2002; Corsetti et al., 2008b). One can easily combine the domestic Euler equation (1.13) with its foreign counterpart and the UIP condition (1.15) to obtain:[21]

$$E_t\Big[\frac{c^*_{t+1}}{c^*_t}\frac{q_{t+1}}{q_t}\Big] = E_t\Big[\frac{c_{t+1}}{c_t}\Big] \tag{2.13}$$

As equation (1.50) imposes a constant value for detrended foreign consumption, it follows that real exchange rate changes are proportional to domestic consumption growth. This explains why the co-movement of c_t and τ_t occurs in figure 2.2a.

To anticipate the Maastricht-constrained optimal plan that will be discussed in section 2.6, we can obviously see that the nominal boundaries will be binding. As the differential between the euro area and the optimal interest rates exceeds 2 percentage points during the first five years, it becomes clear that adopting the single currency without allowing sufficient time for the real convergence process to materialise can be suboptimal.

The strong countercyclical response triggers a fall in aggregate demand, which enables domestic residents to work less, especially in the traded sector. As Edge et al. (2007) extensively discuss, a negative co-movement between productivity growth and hours is a long-established prediction of DSGE models. The relationship have also been confirmed empirically by Galí and Rabanal (2005) in an identified VAR, and by Smets and Wouters (2007, p.601-602) in their Bayesian impulse response analysis. Whereas $l_{H,t}$ displays a

[21]We have neglected the influence of the risk premium term $\Omega()$ for convenience.

persistently lower value relative to the natural rate allocation, the fall in $l_{N,t}$ lasts for one period only. Given the relationship between the real marginal costs in (D.2) and the hump-shaped decrease of the relative price $\rho_{nh,t}$, our numerical results imply that traded sector real marginal costs will be persistently lower. Consequently, the asymmetric response of hours across the two sectors can be attributed to the above transmission channel. Similarly to the response of hours, the disinflation process in the open sector is smooth and persistent and continues to exist as long as the productivity driven catch-up is at work. We find that an unanticipated initial productivity shock of a magnitude of 9% per year results in an optimal 3% traded sector deflation for our chosen parameterisation.

The assumption of a monopolistically competitive market structure contrasts the Balassa-Samuelson model, where traded sector producers are price takers in international markets. Moreover, the presence of nominal rigidities, the forward looking decision making and the role played by monetary policy in influencing the equilibrium allocation are all key differences from the initial static contribution. Despite this, the basic transmission mechanism that causes the relative price of nontraded goods to increase is still at work. Higher productivity growth in the open sector induces the marginal product of labour to change at a higher rate, resulting in larger real wages increases. As there is perfect labour mobility across the economy, nominal wages in the two sectors are equalised. For the labour market to clear in the nontraded sector however, the larger growth rate of nominal wages has to be offset by a higher relative inflation. This enables nontraded sector labour costs to move in proportion to the marginal product of labour $\Gamma_{N,t}$. An alternative explanation is that a higher relative price of nontradables is needed to switch demand towards the expanding sector, whose products are in excess supply. By changing their expenditures patterns in such a way, domestic consumers are able to enjoy a higher utility from the aggregate consumption good. Figure 2.2a indicates that this is exactly the case. Under the optimal plan, nontraded sector inflation displays a hump shaped response that peaks at an annualised level of 6%. Hence, we are able to rationalise a 4 percentage points inflation differential relative to the long-run steady state. The adjustment process until π_N returns to the steady state level takes about 25 years.

In contrast to the Balassa-Samuelson model, the higher relative price of nontraded goods is in our case a byproduct of a higher inflation in the nontraded sector and a disinflation process experienced by manufacturing goods. The prediction of a higher rate of change in nontradable prices is in line with the traditional Baumöl and Bowen (1965) effect, which postulates that countries engaged in a catching-up process will generally experience a relative increase in the price of services.

While the magnitude of the nontraded sector inflation response appears to offset the lower value of $\pi_{H,t}$, the appreciating terms of trade effect causes aggregate inflation to fall in the initial period.[22] However, the subsequent adjustments in τ_t and $\pi_{H,t}$ lead to positive aggregate price changes. The excess inflation differential is of about 3 percentage points, which smoothly dissipates as the real convergence shock subsides. The concern about violating the Maastricht constraints is less problematic in this case, as CPI inflation satisfies the price stability criterion after 10 quarters.

The last important graph we will focus on in this section refers to the net foreign assets position. A large number of studies (Cole and Obstfeld, 1991; Corsetti and Pesenti, 2001; Ghironi, 2006) have emphasised the automatic risk sharing mechanism provided by the terms of trade when the elasticity of substitution between domestic and foreign goods is unitary. If the initial net foreign assets position is zero, then the efficient adjustment of relative prices implies that the current account becomes irresponsive to macroeconomic shocks. To our knowledge, the above result was derived only within one sector economies, where all goods are traded and the steady state is undistorted, and indicated an important equivalence between the complete and incomplete markets allocations in such models. The numerical solution employed here provides further support for the lack of current account adjustment to (permanent) productivity shocks, when the model allows for a distorted steady state and nontraded goods. It further suggests that the limited response of the net foreign position predicated by Sutherland (2002, p.1) is robust.

> "When the elasticity of substitution between home and foreign goods is unity, the trade balance is always close to balance in any case. The structure of international financial markets is therefore largely irrelevant."
>
> (Sutherland, 2002)

The limited interplay between current account fluctuations and the productivity driven catch-up implied by the monopolistically competitive version our model is not entirely in agreement with the persistent current account deficits observed in Emerging Europe that have been documented in figure 1.2. In light of this observation, section 2.5 considers the case of perfect competition in the traded sector. As we shall see, when domestic and foreign goods are made perfectly substitutable, the model predicts that more substantial consumption and current account responses will emerge during periods of high growth.

[22] See equation (B.7).

2.3 Dynamics under Simple Policy Rules

This section discusses how the optimal plan is likely to be implemented in practice, by considering the equilibrium allocation under alternative simple rules. These include the Taylor specification in equation (1.54), a CPI inflation targeting regime and a nominal peg. The performance of a given instrument rule is evaluated from a welfare point of view relative to the Ramsey plan, by computing its welfare cost conditional on the initial state of the economy. The latter corresponds to the pre-convergence steady state in Appendix F and is identical for all the policy rules considered. Moreover, it corresponds to the initial state of Ramsey program.

2.3.1 Measuring Welfare Costs

To measure the welfare implications of alternative monetary policy regimes, we follow the compensating variation approach discussed in Schmitt-Grohé and Uribe (2006). Let the conditional value functions associated with the Ramsey policy and with an alternative regime A be defined by:

$$V_0^R = E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^R, l_t^R)$$

$$V_0^A = E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^A, l_t^A)$$

The conditional welfare cost of adopting policy regime A, instead of regime R, is measured by the amount of lifetime consumption stream the agent is willing to give up under policy regime R, in order to be as well off as under the alternative regime A. Hence, the welfare cost (denoted below by λ^c) corresponds to the concept of compensating variation in microeconomics. In this case, it is defined as :

$$V_0^A = E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^R(1-\lambda^c), l_t^R)$$

The functional form we adopt for the period utility function results in a value function differential given by:

$$V_0^A - V_0^R = \frac{1}{1-\beta} ln(1-\lambda^c)$$

From where the compensating variation is equal to:

$$\lambda^c = 1 - e^{(1-\beta)(V_0^A - V_0^R)} \tag{2.14}$$

2.3.2 The Optimal Simple Rule

The Ramsey plan is only partially informative about how monetary policy should be implemented in practice. After determining the optimal allocation, we aim to make our findings relevant for policy evaluation and implementation. Following Schmitt-Grohé and Uribe (2005, 2006), the focus is oriented towards interest rate rules that are simple and operational. As argued by the authors, simplicity means that the rule involves a reaction to a small number of observable macroeconomic variables. On the other hand, a policy rule is operational if it guarantees the uniqueness of the rational expectational equilibrium and if its optimised feedback coefficients are restricted in the [-6,6] interval.

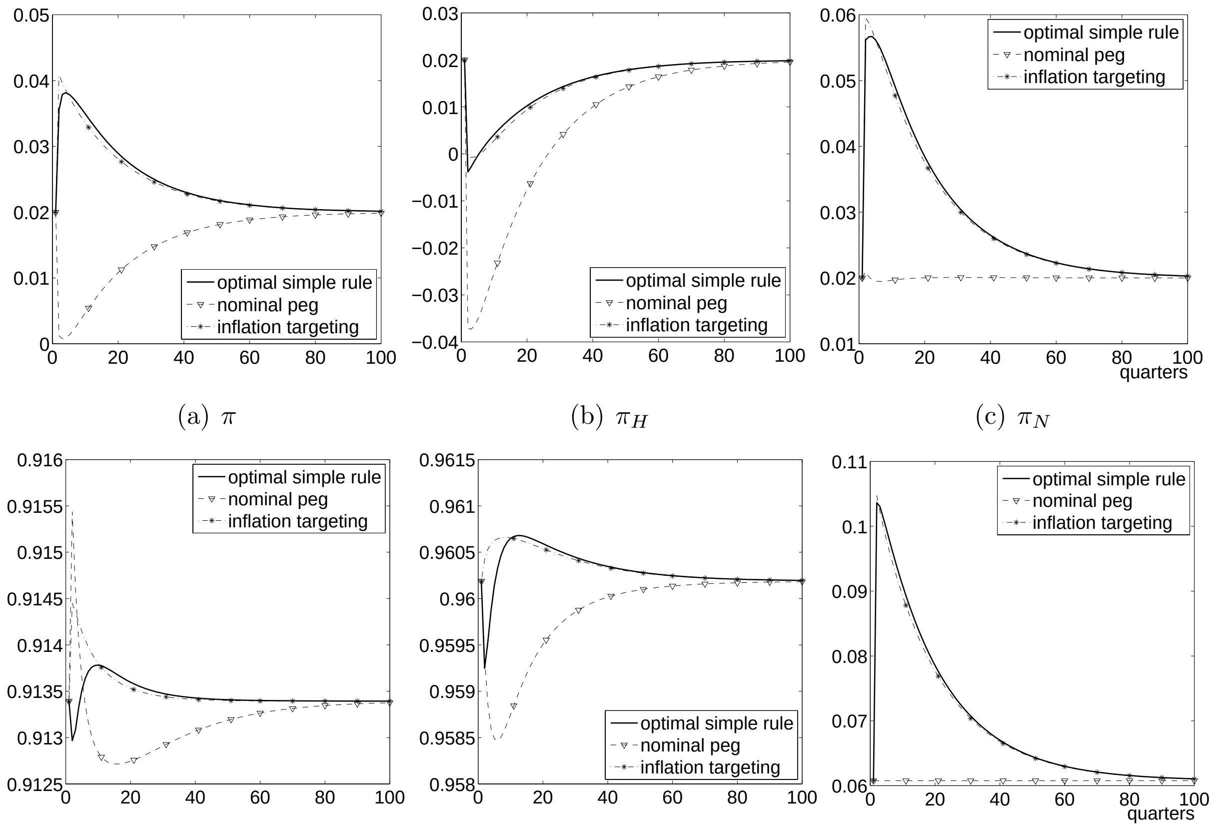
We consider the optimal parameterisation of the following simple rule :

$$\ln\Big(\frac{1+i_t}{1+i}\Big) = \chi\ \ln\Big(\frac{1+i_{t-1}}{1+i}\Big) + (1-\chi)\ \Big[\alpha_\pi \ln(\frac{\pi_t}{\pi}) + \alpha_y \ln(\frac{y_t}{y})\Big] \tag{2.15}$$

This class of reaction functions is of particular importance, for it involves the response to a few observable macroeconomic variables that are typically monitored by central banks. In setting up the decision rule, the policy maker responds to the deviation of CPI inflation from target and to the trend deviation of aggregate output from its steady state value. Following most of the recent literature on monetary policy, we also allow for the possibility of smoothing interest rate movements.

The optimal simple rule implies a large response to contemporaneous output and inflation, although the welfare surfaces with respect to the iterations on these two parameters are relatively flat. When the numerical search for the optimal feedback coefficients is unconstrained, we find an optimal value of $\alpha_\pi = 50.1732$, $\alpha_y = 71.2954$ and $\chi = 0$. Hence, smoothing interest rate changes under unbalanced growth induces a deterioration of welfare.

The transition paths of the optimised simple rule are presented in figures 2.2a and 2.5. As the adjustment of the instrument variable i_t shows, the central bank's response is too moderate in the first year. While the Ramsey planner increases the nominal interest rate to 18% on impact, a 10% adjustment is observed in the case of the generalised Taylor rule. The differential is even larger when we compare the transition paths of real interest rates. In spite of these short-term differences, the transition paths of most variables soon correspond to the optimal allocation. As a consequence, it can be reasonably inferred that most of the welfare gains we report in table 2.1 under the optimal full commitment policy arise as a result of the terms of trade externality. The positive values of the optimal feedback coefficients reflect the necessity to respond more to aggregate inflation and output when it is optimal to do so (e.g. from period 2 onwards).



(a) π (b) π_H (c) π_N

(d) l (e) c (f) i

Figure 2.5: Simple policy rules

Table 2.1: Optimal monetary policy - welfare costs

Interest-Rate Rule	$\frac{1+i_t}{1+i} = \chi \, ln(\frac{1+i_{t-1}}{1+i}) + (1-\chi)(\alpha_\pi \frac{\pi_t}{\pi} + \alpha_y \frac{y_t}{y}) + \alpha_s \frac{S_t}{\bar{S}}$					
Feedback coefficients	α_π	α_y	χ	α_s	$\bar{S}$	Conditional welfare cost ($\lambda^c \times 100$)
Ramsey policy	-	-	-	-	-	0
Optimised simple rule	50.1732	71.2954	0	-	-	0.000695
Optimised operational rule	6	6	0	-	-	0.000722
Optimised CPI inflation targeting	2.0071	-	-	-	-	0.000949
Optimised nominal peg	-	-	-	700	1.0235	0.010325
Nominal peg at the initial state	-	-	-	700	1	0.011597
Simple Taylor rule	1.5	0.5	-	-	-	0.004777

Table 2.1 summarises the welfare implications of choosing alternative simple rules. With the exception of the last two rows, all the feedback coefficients reported above represent

optimised values that were computed numerically using the Nelder-Mead algorithm (see Lagarias et al., 1998). According to our results, the compensating variation needed to make domestic consumers indifferent between the optimised simple rule and the Ramsey plan equals 0.0007 percent of their detrended lifetime consumption streams.

Similarly to Schmitt-Grohé and Uribe (2005, 2006) and Leith et al. (2012), we also consider reaction functions that are operational, in the sense that they restrict the search for the welfare maximising feedback coefficients to the [-6,6] interval. The constraint imposed on the feasible region of the policy parameters makes such specifications appealing in a practical sense, for they can be more easily explained to the general public. The optimised coefficients of the operational rule were found equal to $\alpha_\pi = 6$, $\alpha_y = 6$ and $\chi = 0$. As the conditional welfare cost of moving from the unconstrained to the operational simple rule has an order of magnitude of 10^{-5}, we conclude that the optimal simple rule reported here can be readily implemented in practice.

2.3.3 Strict CPI Inflation Targeting

The second type of reaction function we examine is that of a strict CPI inflation targeting regime:

$$ln\Big(\frac{1+i_t}{1+i}\Big) = \alpha_\pi \; ln\Big(\frac{\pi_t}{\pi}\Big) \tag{2.16}$$

Within this class of rules, we find an optimised feedback coefficient $\alpha_\pi = 2.0071$. The computed transition paths depicted in figure 2.5 closely resemble the ones obtained under the optimal simple rule. As a consequence, it is not surprising that the welfare costs of adopting one regime rather than the other are relatively low (see table 2.1).

However, by comparing figures 2.2a and 2.5, it becomes clear that certain differences exist with respect to the optimal allocation. Aggregate inflation jumps to a higher, rather than a lower, level in the initial period. We notice that the inflation differential caused by the convergence shock is one percentage point lower. The disinflation process in the traded sector is less pronounced, whereas consumption and hours display initial responses of opposite sign. All in all, the welfare losses associated with an inflation targeting rule are triggered by the initial divergent responses. A similar assessment of why a strict CPI inflation targeting is suboptimal can be made. Specifically, a policy that targets consumer prices does not achieve a sufficiently countercyclical response in the initial period. Since the monetary policy stance is too loose, the domestic monetary authority does not internalise the detrimental wealth effects that relative price misalignments have on domestic welfare. Because aggregate demand is much higher than it would be optimal, home residents enjoy a higher level of aggregate consumption, but they also significantly increase their labour effort. The utility loss caused by working more exceeds the utility benefit of higher consumption.

A reasonable advice can be given to policy makers who are willing to join the ERM II mechanism while implementing an inflation targeting rule. Bearing in mind the conditional response of aggregate inflation, the monetary integration decision should be considered only when the inflationary effects of real convergence are sufficiently limited. If the foreign inflation rate defining the price stability criterion has a value between 1.5% and 2%, a provisional waiting period of 10 to 20 quarters would guarantee that the relevant Maastricht criterion is not violated. The policy advice also takes into account the conditional responses of i_t and S_t, which are found to meet the SGP restrictions after the suggested 20 quarters interval.

2.3.4 Nominal Peg

The third type of rule we consider is a nominal peg, implemented by a policy maker who strongly reacts to variations in S_t. Accordingly, the exchange rate feedback parameter is calibrated at $\alpha_s = 700$, a value that is sufficiently large to prevent movements away from the initial state.

$$ln\Big(\frac{1+i_t}{1+i}\Big) = \alpha_s \; ln\Big(\frac{S_t}{S_{t-1}}\Big) \tag{2.17}$$

In line with the celebrated trilemma in international economics, a commitment to stabilise nominal exchange rate fluctuations under perfectly mobile capital flows triggers a loss of domestic monetary policy sovereignty. The effect represents a simple confirmation of the UIP condition. A credible stabilisation of nominal exchange rate movements can only occur if domestic and foreign interest rates are equal in all periods. Moreover, as the interest rate panel in figure 2.5 shows, the constant level of the policy instrument is a direct result of the flexible price allocation we imposed on the foreign block.[23]

Whereas the optimal response was found to be strong and persistently countercyclical, the requirement to align domestic and foreign interest rates brings about a substantial divergence of the nominal peg allocation as compared to the Ramsey plan. It follows that an early adoption of a fixed exchange rate regime has the adverse effect of causing a relatively loose monetary policy stance.

The divergent interest rate path is also reflected in the equilibrium properties of the

[23] See eqs. (1.49)-(1.50).

dynamic system, whose response is substantially different from the optimal outcome. From this point of view, our analysis signals a potential Ramsey-nominal peg policy dissonance, a result that was previously found by Lama and Medina (2007, p.22) in a related model. Figures 2.5 and 2.6 contrast the performance of the fixed exchange rate allocation relative to the optimal simple rule and the Ramsey plan, respectively.

One essential message which emerges is that the monetary policy regime plays a crucial role in shaping the relationship between nominal and real convergence. Whereas the constrained-efficient expenditure switching effects are triggered by a mixture of nominal depreciation and traded sector disinflation, a fixed value of the nominal exchange rate implies that the above adjustment can only be achieved through changes in the price of domestic goods. Intuitively, when domestic goods are relatively expensive in international markets, home residents have to decrease the price of their products. By doing so, they suffer a significant reduction in their wealth, which results in a decrease in aggregate demand. The reduction is domestic absorption is in fact high enough to counterbalance the expansionary effects induced by monetary policy. This is why a persistent fall in hours and consumption is observed in figure 2.6. An alternative way of understanding the reasons why traded sector disinflation occurs is by looking at the UIP condition. In this sense, the commitment to a peg in equation (1.53) implies a negative correlation between the excess traded sector growth and the deviation of $\pi_{H,t}$ from its foreign counterpart.[24]

Under a fixed exchange rate arrangement, unbalanced productivity growth still causes nontraded sector prices to grow at a faster pace, although this does not necessarily mean that nontradables or the economy experience positive price changes. The muted response of nontraded inflation can be attributed to the transmission of the negative wealth effects across sectors. As a result of the sector specific price dynamics, the economy experiences a severe disinflation process. In fact, the transition path of π_t is negatively correlated with the optimal responses.

Under monopolistic competition in the traded sector, our results suggest that a fixed exchange rate regime will always meet the Maastricht convergence criteria. This is because: (i) domestic and foreign interest rates are equal; (ii) the nominal exchange rate is stable; (iii) the CPI inflation is lower than the 3.5% price stability boundary in all periods. Given that euro adoption is an important goal for monetary authorities in Emerging Europe, the fact that a nominal peg does not violate the ERM II convergence criteria clearly represents a desirable property of this regime. Yet, as we can observe from table 2.1, the welfare performance of a nominal peg is substantially weaker as compared to that of

[24] The relationship between changes in S_t and the variables we refer to is also reproduced in equation (2.19) on the next page.

the inflation targeting and optimal allocations. Our findings suggest that stabilising the nominal exchange causes consumers to forgo 0.01 percent of their detrended consumption streams. Moreover, the welfare loss associated with such a regime is augmented by an order of magnitude relative to the best performing simple rule.

2.3.5 The Optimal Level of the Peg

The previous analysis assumed that the central bank fixes the nominal exchange rate at the initial state S_{-1} level, normalised at 1. In this section, we relax this assumption and offer more flexibility to the policy maker in choosing an optimal value of $\bar{S}$. In doing so, we specify a general fixed exchange rate rule, while maintaining the calibrated value of α_s:

$$ln\Big(\frac{1+i_t}{1+i}\Big) = \alpha_s \; ln\Big(\frac{S_t}{\bar{S}}\Big) \tag{2.18}$$

The nominal exchange rate is added to the system of equations as a new state variable, whose law of motion was previously derived as:[25]

$$\frac{S_t}{S_{t-1}} = \frac{1+g_{H,t}}{1+g^*}\frac{\pi_{H,t}}{\pi^*}\frac{\tau_t}{\tau_{t-1}} \tag{2.19}$$

Without loss of generality, we normalise the initial state at $S_{-1} = 1$.

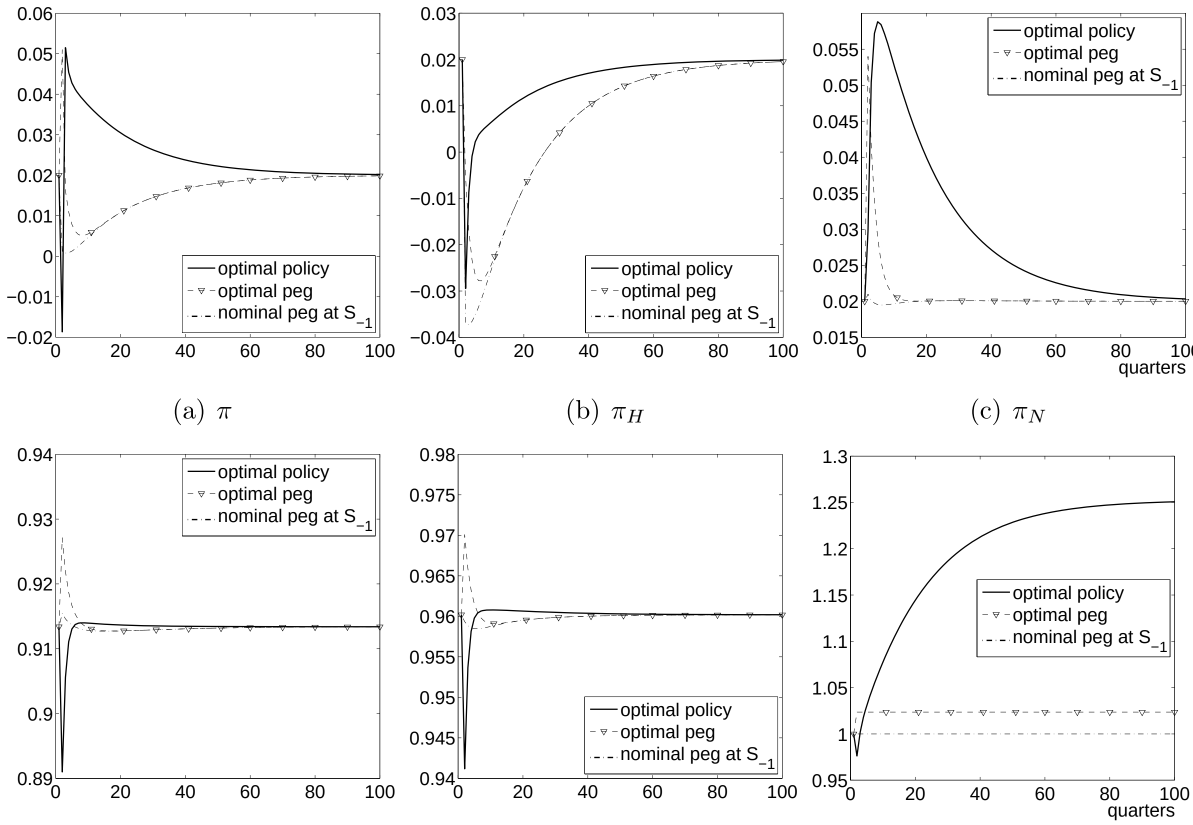
Conditional on the chosen calibration, the assumption of monopolistic competition in the traded sector implies that international relative prices will experience a *depreciating* trend in our model.[26] While challenges along these lines to the Balassa-Samuelson proposition have been known at least since the work by Benigno and Thoenissen (2003), the depreciating effect that productivity shocks may have on the nominal exchange rate has been only recently formalised in a theoretical model by MacDonald and Ricci (2007).

The question we try to answer is the following. If the economy is expected to experience a trend in international relative prices and the policy maker is bound by an institutional arrangement, such as joining the European Monetary Union, to fix the nominal exchange rate immediately, what is the optimal level of the peg that should be implemented?

Figure 2.6 contrasts the allocations that arise under the two classes of fixed exchange rate arrangements considered. We relate our findings to the Ramsey plan.

[25] See section 1.3 on Monetary policy.

[26] See page 57 and Lein et al. (2008, p.230) for related discussions.



(a) π (b) π_H (c) π_N

(d) l (e) c (f) S

Figure 2.6: Fixing the nominal exchange rate: comparison

It can be noticed from transition path of S_t that the nominal exchange rate depreciates by 25% under the optimal plan. Given the decision rule specified in equation (2.18) and the expected depreciating trend, we find that welfare gains do arise if the policy maker allows a moderate devaluation (2.35%)[27] and then fixes the variable at that level. Compared to the simple peg arrangement, there is some level of divergence in the initial period which involves a higher level of aggregate demand. By allowing a moderate degree of devaluation, the policy maker offsets some of the deteriorating wealth effects we mentioned in the case of the simple peg. Specifically, a higher level of the exchange rate allows residents to earn more by making their exports more competitive abroad. As a result of this positive income effect, the economy experiences an increase in consumption, hours worked and inflation. However, the binding arrangement of maintaining the nominal exchange rate fixed in the future still requires a disinflationary, welfare deteriorating adjustment. This explains why the conditional equilibria under the simple and optimal peg soon overlap.

[27]The fminsearch routine generated an optimised value of $\bar{S}$ equal to 1.0235.

2.4 Sensitivity Analysis

In this section, we aim at quantifying the significance of the results when some of the features of the baseline model are relaxed. Specifically, we check the sensitivity of the positive statements about optimal policy along two dimensions. First, we assign different values to the price stickiness parameters. Second, we compare how the results change when the long-run relative productivity ratios are stabilised at different levels.

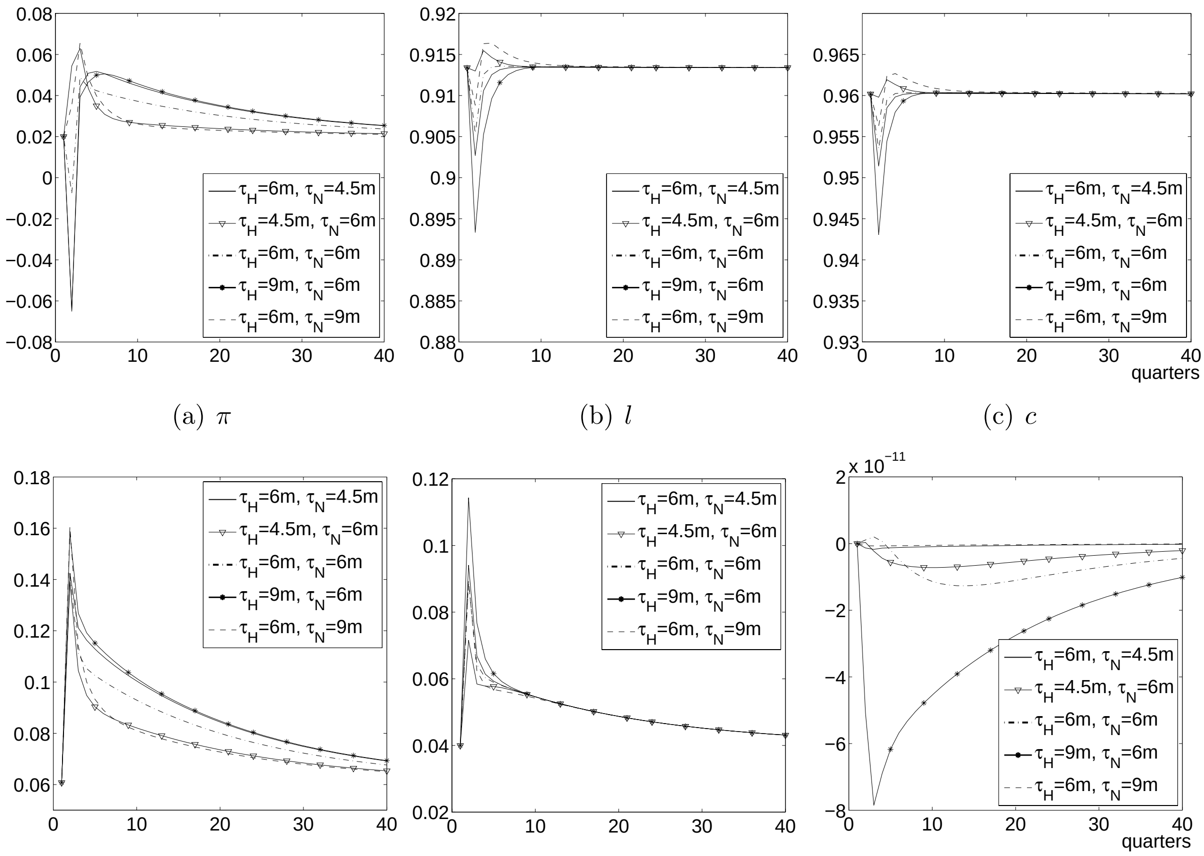
2.4.1 Nominal Rigidities in the Goods Market

The baseline calibration implied an average duration of nominal price contracts of 11 months. In determining the degree of nominal inertia, we invoked the equivalence between the Calvo and Rotemberg price setting mechanisms up to a first order of approximation. This correspondence will prove important throughout this section, given that all results will be presented in terms of the average duration of the sector-specific Calvo contracts - τ_H and τ_N. The alternative parameterisations we consider here are consistent with lower degrees of nominal inertia, as the frequency of price changes can take values of either four and a half months, six months or nine months.[28] By choosing the above values, we aim to make the sensitivity analysis compatible with the evidence on nominal rigidities for the euro area (Fabiani et al., 2005). We first examine the qualitative features of the optimal plan under different combinations of τ_H and τ_N.

The dynamic responses presented in figure 2.7 are qualitatively similar to the baseline case. Owing to the terms of trade externality, a *higher* level of traded sector nominal inertia accentuates the disinflation process in that sector. On the other hand, an increase in τ_N brings about an inflationary effect in the nontraded sector. Because of the above heterogeneity, no explicit relationship can be established between the dynamics of CPI inflation and the degree of price stickiness. In most cases, however, aggregate inflation experiences an initial fall followed by a hump shaped response, which is similar to the baseline findings. Nominal rigidities appear to have an important influence on the length of time over which inflation is stabilised.

When price adjustment costs are lower in the traded sector, detrended consumption and hours display a different response. This is because a low degree of nominal inertia reduces the scope for engineering a terms of trade improvement. When prices are relatively flexi-

[28]The mapping between the two parameter sets is as follows: $\tau_{H,N} = 4.5m \rightarrow \psi_H = 4.5, \psi_N = 3$; $\tau_{H,N} = 6m \rightarrow \psi_H = 12, \psi_N = 8$; $\tau_{H,N} = 9m \rightarrow \psi_H = 36, \psi_N = 24$.



(a) π (b) l (c) c

(d) i (e) r (f) nfa

Figure 2.7: The optimal policy plan under alternative nominal adjustment costs

ble, the contraction in demand is less severe and this induces higher levels of consumption and hours.

The countercyclical response of nominal and real interest rates is also consistent with our main findings. The duration of price contracts affects both the peak values of the policy instrument, which varies in the range of $12 - 17\%$, and the persistence of the transition adjustment. Higher levels of nominal rigidities in the traded sector are associated with a longer-lasting nominal convergence phenomenon. Similarly to the baseline calibration, real interest rates are stabilised only after a small number of quarters.

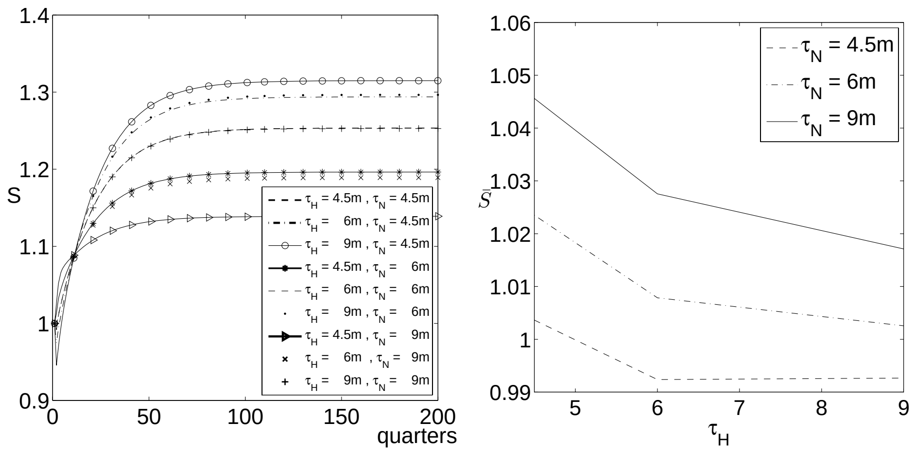
In table 2.2, we report the second type of sensitivity check we conduct. The aim in this case is to verify whether our welfare results are robust. We find that the welfare losses of a fixed exchange rate regime, either optimal or not, continue to have a higher order of magnitude than the optimal simple rule. The latter corresponds to the specification in (2.15) , whose optimised feedback coefficients for specific values of τ_H and τ_N are available upon request.

$\tau_N \backslash \tau_H$	4.5 m			6 m			9 m		
	OSR	$\bar{S}$ FER	S_0 FER	OSR	$\bar{S}$ FER	S_0 FER	OSR	$\bar{S}$ FER	S_0 FER
4.5 m	0.000085	0.000900	0.000906	0.000840	0.002799	0.002843	0.003286	0.009145	0.009211
6 m	0.000044	0.000766	0.001118	0.000210	0.002348	0.002405	0.001780	0.007851	0.007860
9 m	0.000230	0.000813	0.002722	0.000187	0.002058	0.002994	0.000506	0.006565	0.007076

*OSR and FER represent abbreviations for the optimal simple rule and a fixed exchange rate regime.

Table 2.2: Welfare costs relative to the Ramsey plan, $\lambda^c \cdot 100$

Table 2.2 also suggests that the welfare losses of all simple rules are monotonically increasing in τ_H. When the degree of traded sector nominal inertia is high, there is a larger scope for the Ramsey planner to make effective use of the terms of trade externality in the initial period. As a result, the corresponding welfare gains associated with the optimal allocation will be larger.



(a) trend depreciation of S (b) $\bar{S}$

Figure 2.8: Trend depreciation under the Ramsey plan and the optimal peg

The first panel in figure 2.8 displays how the trend behaviour of S is affected by variations in τ_H and τ_N. Our results suggest that a costly price adjustment in the traded (nontraded) sector is associated with a more (less) pronounced depreciation of the nominal exchange rate. The explanation of why a higher degree of traded sector nominal inertia causes a higher nominal devaluation is identical to the one we put forward in our baseline parameterisation. Moreover, panel (b) in the same figure indicates a robust negative (positive) relationship between the optimal level at which the nominal exchange rate should be fixed and the degree of price stickiness in the traded (nontraded) sector.

2.4.2 Persistence of the Productivity Growth Shock and the Case of Full Convergence

Little can be said about what long-run relative productivity ratios are likely to be empirically relevant in the Czech Republic. The earlier EU accession experiences of Portugal, Greece or Ireland revealed that the European integration process can result in both higher and lower relative standards of living after 20-30 years. While technological transfers and more efficient institutions are important determinants of the catch-up phenomenon, there is one controversial aspect involved in modelling a forward-looking phenomenon such as real convergence. Specifically, the exogenous productivity process depends on a priori considerations regarding the future supply-side adjustment over a prolonged period of time. In this section, we address some of the potential concerns that might be raised with respect to the baseline convergence specification we adopted, which implied a long-run relative productivity ratio of 90%. The robustness of our results is examined in relation to a different modelling approach of the real convergence phenomenon in which traded sector productivity fully converges to its foreign counterpart. In addition, we consider the effects of an alternative parameterisation of $\varrho = 0.925$ that is consistent with a long-run relative productivity ratio of 80%. Throughout the remaining pages of this chapter, the long-run relative relative productivity ratios implied by the alternative real convergence adjustments we look at will be represented by $\bar{X}$.

Full convergence of traded sector productivity in levels

We resume the discussion on the alternative concept of real convergence, previously introduced in section 1.2.4.2. Back then, we mentioned that the productivity driven catch-up can be modelled by specifying an adjustment process of the relative productivity *levels*. This contrasts the stance we took in the main simulation, which had in mind a dynamic equation of the traded sector *growth rate*.

$$(X_t - \mu) = \omega(X_{t-1} - \mu) \tag{1.25}$$

In the above process, $X_t = \frac{\Gamma_{H,t}}{\Gamma_t^*}$ denotes the domestic traded - foreign productivity gap at time t, while μ and $1 - \omega$ stand for the long-run mean of X_t and the speed of adjustment at which deviations from the mean are corrected. From this point of view, the error correction mechanism in equation (1.25) closely resembles a standard $AR(1)$ process. Note that, when the initial productivity gap is taken as given and the long-run mean is imposed based on a priori considerations, the calibration of ω generates an *endogenous* growth shock.

We choose an initial value of $X_0 = 0.64$, which intends to match the ratio of GDP per capita between the Czech Republic and the euro area prior to the recent real convergence phenomenon.[29] Moreover, our aim is to check the sensitivity of the results when full convergence is achieved ($\mu = 1$) and the productivity gap is closed at a speed of adjustment $(1-\omega)$ of 10 per cent per year.[30]

Given the restriction imposed on the long-run mean of the domestic-foreign productivity gap, the convergence equation can be represented as:

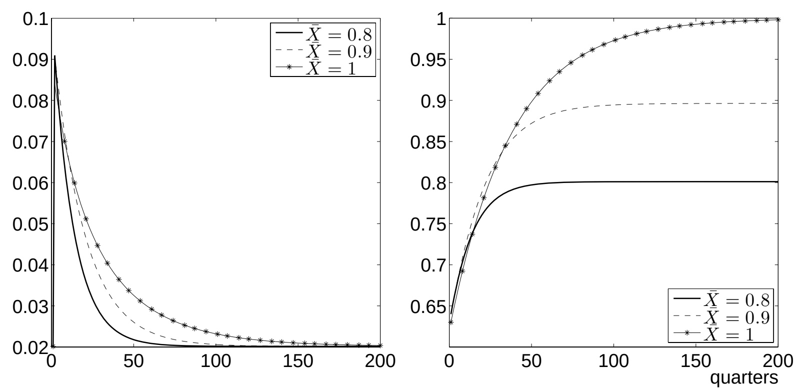
$$X_t = 1 - \omega + \omega X_{t-1} \tag{2.20}$$

Dividing by X_t and using the fact that $\frac{X_t}{X_{t-1}} = \frac{1+g_{H,t}}{1+g^*}$ gives:

$$1 = \frac{1-\omega}{X_t} + \frac{\omega(1+g^*)}{1+g_{H,t}} \tag{2.21}$$

After other simple manipulations, the traded sector growth rate becomes a function of the current productivity level and other exogenous parameters:

$$1 + g_{H,t} = \omega(1+g^*)\frac{X_t}{X_t - 1 + \omega} \tag{2.22}$$



(a) g_H (b) X

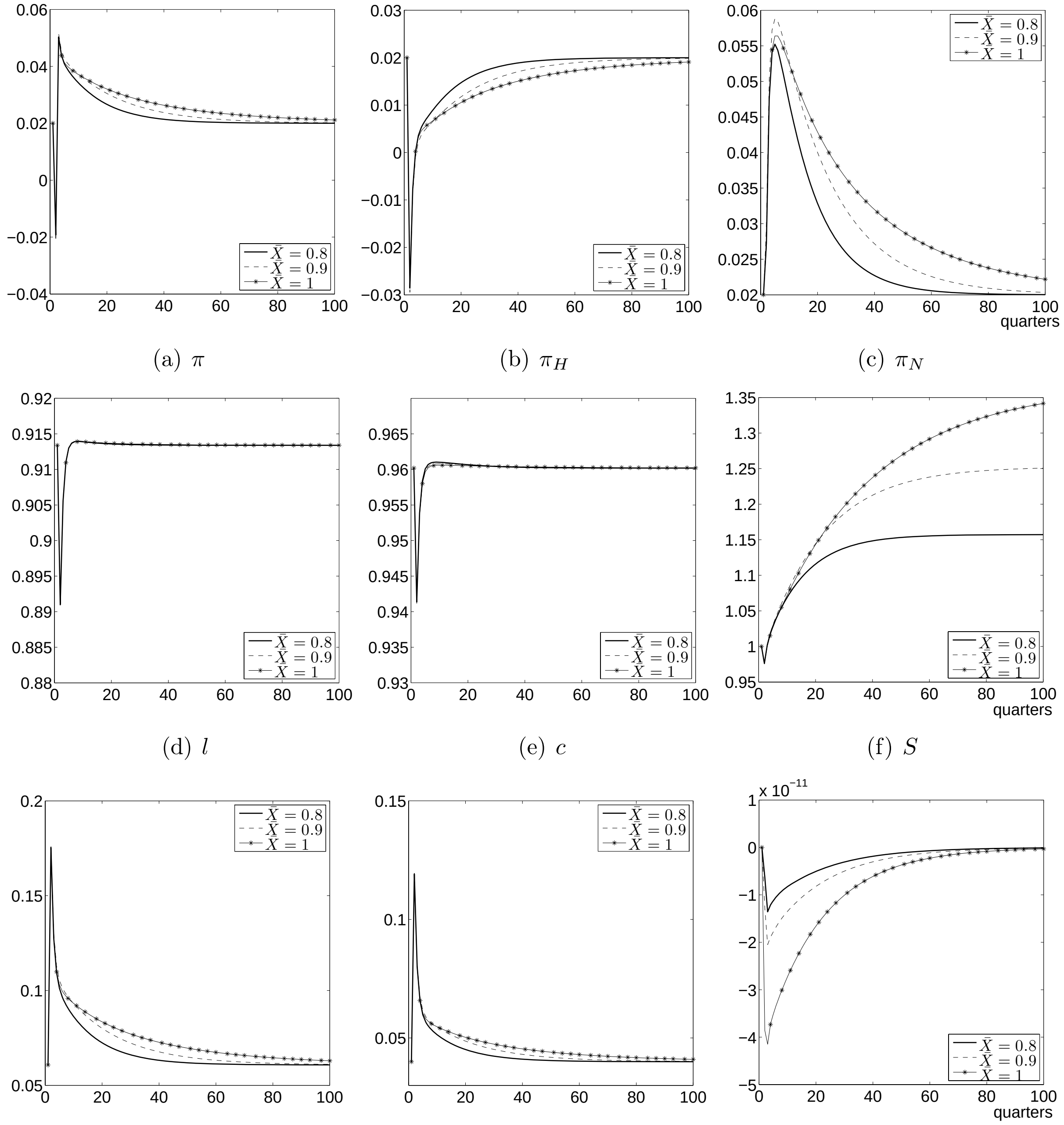
Figure 2.9: Long-run productivity adjustment scenarios

One can observe from figure 2.9 that the specific parameterisation of the initial productivity gap X_0 gives rise to an initial productivity growth differential that has a similar (but slightly lower) magnitude as compared to the convergence in growth rates scenarios.

[29] see Figure 1.1.

[30] Since the model uses quarterly data, the calibration imposes $\omega = 0.974$.

However, the growth rate's dependence on the current productivity level will generally imply a different curvature of the adjustment process.



(a) π (b) π_H (c) π_N

(d) l (e) c (f) S

(g) i (h) r (i) nfa

Figure 2.10: The optimal policy plan under alternative real convergence scenarios

The results of the second sensitivity check we conduct are presented in figure 2.10. As the transition paths are qualitatively similar, our analysis suggests that the system's response is robust to changing the specification of the growth process and to varying its degree of persistence. One important message that emerges is that significant differences can only be noticed for nominal variables, whereas real quantities are largely independent of the persistence parameter. Given the constraints imposed on the optimal policy problem, it is clear that Ramsey planner can only engineer a short-term contraction in aggregate demand which depends mainly on the initial growth differential. To this end, the optimal plan is characterised by similar optimal deviations of consumption and hours from the natural rate allocation, which are brought about by roughly equal short term adjustments in the policy instrument during the first periods. Likewise, optimal policy entails an initial nominal exchange rate appreciation, which is robust across all specifications. Based on these findings, one important normative implication emerges from our analysis. Specifically, the welfare gains the can be obtained from responding optimally to the convergence shock are possible only in the short-run. Moreover, holding the initial convergence shock constant, different long-run productivity adjustment ratios do not result in higher welfare gains relative to the natural rate allocation.

On the other hand, the alternative convergence scenarios have a more palpable effect on the adjustment of nominal variables. For example, the higher the long-run relative productivity ratios, the larger the optimal disinflation (inflation) process of the traded (nontraded) sector is. Noteworthy differences can be also noticed for the policy responses, which entail a more persistently countercyclical adjustment in the medium to long-run.[31] Given the higher paths of nominal and real interest rates, it is clear that the optimal plans will imply more depreciated long-term values of the nominal exchange rate.

In relation to meeting the Maastricht inflation criterion, the initial adjustment of π_t appears to depend primarily on the size of the growth shock and less on the persistence parameter. In order to implement a policy that simultaneously maximises welfare and satisfies the $\pi_t \leq 3.5\%$ constraint, the decision to participate in the ERM II mechanism should be postponed by approximately five years. On the other hand, meeting the exchange rate criterion does not appear to be a concern, as the trend depreciation implied by our model falls within the 15% for any 2 year theoretical intervals.

2.5 Perfect Competition in the Traded Sector

As we briefly discussed in the introduction of this thesis, the real convergence experience of emerging European economies was marked by persistent current account deficits and diverse trends in relative prices. Whereas the baseline model could well apply to Poland and Hungary, which generally displayed depreciating trends in nominal and real exchange

[31] See the differences that occur after from period 10 onwards.

rates between 1998 and 2010, the Czech koruna appreciated by more than 30 percent. In order to reconcile our theoretical experiments with this evidence, it is therefore necessary to consider a version of our model which predicts downward movements in relative prices, while also allowing for optimal current account imbalances. The particular case to be examined in this section refers to an alternative market structure in the traded sector, which is now populated by a large number of competitive producers that are price takers in international markets. Perfect competition means that domestic and foreign varieties are perfectly substitutable and that prices are fully flexible. As we shall see, the absence of nominal rigidities in the traded sector, which is also a feature of the baseline Balassa-Samuelson model, brings many new insights to our analysis. For instance, the fact that the elasticity of substitution between domestic and foreign goods is infinite will imply that the current account channel is no longer switched off. As a result, the wealth effects triggered by the productivity growth shock induce more substantial jumps in domestic consumption, leading to significant borrowing from abroad.[32] Since in this alternative setup the terms of trade are always equal to one and the external distortion fades away, the optimal plan will be mainly concerned with redressing the negative effects caused by the monopolistic distortion in the nontraded sector. Before addressing these topics in more detail, we first consider the basic changes that must be made to our model in order to implement this alternative real convergence scenario. The analysis presented in this section should be kept in mind, as the next section will extend it by looking at the Maastricht constrained optimal policy.

In Appendix C we have formally shown that only two values of the trade elasticity of substitution - either unitary or infinite - allow for a model detrending procedure if perfect labour mobility is assumed. The following derivations demonstrate how the alternative market structures examined throughout this chapter are nested within a more general CES specification.

Assume that the tradable consumption index is defined according to an Armington aggregator of domestic and foreign goods:

$$C_{T,t} = \left[\theta^{\frac{1}{\zeta}} C_{H,t}^{\frac{\zeta-1}{\zeta}} + (1-\theta)^{\frac{1}{\zeta}} C_{F,t}^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}} \tag{2.23}$$

By solving a standard cost minimisation problem, the following expression can be obtained for the tradable price index:

$$P_{T,t} = \left[\theta P_{H,t}^{1-\zeta} + (1-\theta) P_{F,t}^{1-\zeta}\right]^{\frac{1}{1-\zeta}} \tag{2.24}$$

[32]It is precisely in such circumstances with jumps in detrended consumption where the perfect foresight, nonlinear solution method we adopt is the only one applicable.

The model we developed in Chapter 1 imposed that the elasticity of trade substitution ζ be equal to one. We now consider the effects of taking the limit of (2.23) as $\zeta \to \infty$.

When domestic and foreign goods are perfectly substitutable, the traded good is a linear combination of $C_{H,t}$ and $C_{F,t}$ that is independent of the parameter θ:

$$\lim_{\zeta \to \infty} C_{T,t} = C_{H,t} + C_{F,t} \tag{2.25}$$

We can determine the input demand functions by minimising the total expenditure $P_{H,t}C_{H,t} + P_{F,t}C_{F,t}$ subject to the production function in (2.25). It is straightforward to show that the prices of domestic and foreign goods are always equal if perfect substitutability is imposed:

$$P_{T,t} = P_{H,t} = P_{F,t} \tag{2.26}$$

As a result, the current setup behaves as if there was only a single traded good produced both at home and abroad. For notational consistency, we label the traded good with H. Its price is determined in international markets, meaning that the effective terms of trade are always equal to 1:

$$T_t = \frac{P_{F,t}}{P_{H,t}} = 1 \text{ and } P_{H,t} = S_t P_t^* \tag{2.27}$$

By expressing the last condition in first differences, it follows that changes in the nominal exchange rate are fully determined by the domestic traded and foreign inflation rates:

$$\frac{S_t}{S_{t-1}} = \frac{\pi_{H,t}}{\pi_t^*} \tag{2.28}$$

The remaining modification to the baseline model concerns the traded sector real marginal cost, which is now equal to unity:

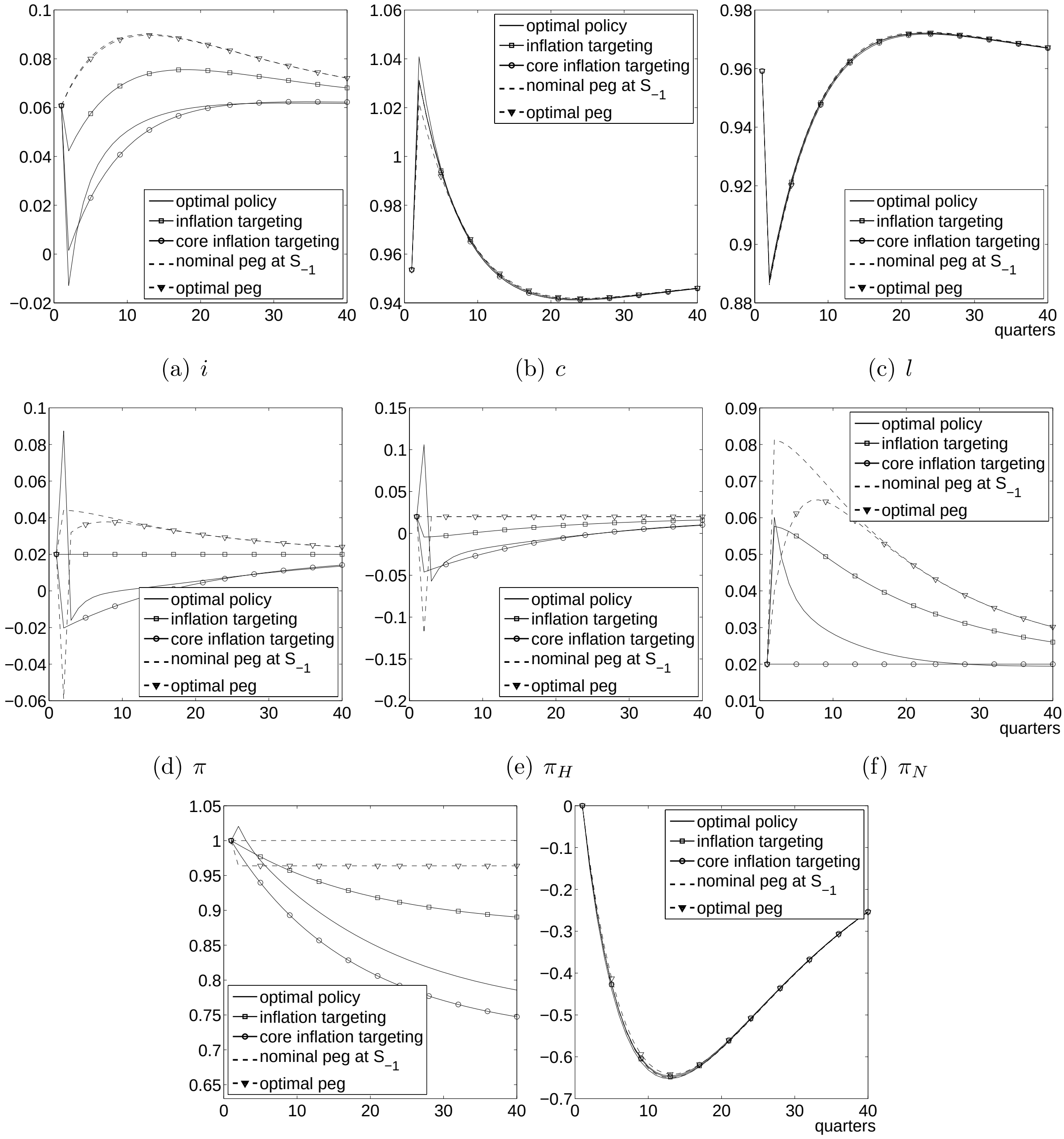
$$mc_{H,t} = w_t R_{NH,t}^{1-\upsilon} \frac{1}{\Gamma_{H,t}} = 1 \tag{2.29}$$

The alternative representations in equations (2.27)-(2.29) can be substituted for throughout Appendices A and B to obtain the structural model with perfect competition in the traded sector. Since the resulting modifications are quite trivial, we do not discuss them any further.[33] Instead, we turn our attention to figure 2.11, where the transition paths under the optimal plan and the alternative simple rules are displayed.[34] The latter are

[33]For instance, aggregate inflation is given by: $\pi_t = \pi_{H,t}^{\upsilon} \pi_{N,t}^{1-\upsilon}$ etc.

[34]For determining the first order conditions of the Ramsey problem under perfect competition, we use the Matlab symbolic differentiation routines developed by Levin et al. (2006).

represented by: (i) a CPI inflation targeting rule; (ii) a core inflation targeting rule, where the monetary authority responds to inflation in the sticky price (nontraded) sector; (iii) a nominal peg that fixes the exchange rate at the initial state; (iv) an optimised peg, where the level at which the nominal exchange rate should be stabilised is chosen optimally. Notice that the open economy Taylor rule is not considered in this section, mainly because it is welfare-dominated by a core inflation targeting rule.



(a) i (b) c (c) l

(d) π (e) π_H (f) π_N

(g) S (h) nfa

Figure 2.11: Perfect competition in the traded sector. Dynamics under optimal policy and alternative simple rules

The equilibrium allocations of real variables reveal that, by moving from imperfect to perfect competition in traded sector, considerable differences stand out. First, whereas the baseline real convergence scenario entailed marginal variations in consumption and hours, the responses of all real variables display much larger amplitude now. In this sense, one can observe that detrended consumption optimally jumps from 0.96 to 1.04 on impact and has an initial variation that is four times larger as compared to the marginal drop in figure 2.2a. The essential explanation for the consumption boom involves the elasticity of substitution between domestic and foreign goods, which is no longer restricted to one. As a result, the income and substitution effects shaping the intertemporal consumption profile do not offset each other as in the monopolistically competitive case. This observation gives rise to a second important difference in that the current account responds to the real convergence shock. Notice that the jump in c_t is financed by issuing foreign currency denominated bonds, which triggers a large accumulation of foreign debt.[35] The decrease in the net foreign assets position is more gradual and reaches its lowest point at a level of 60% of GDP. Hence, one implication of this adjustment scenario is that the persistent current account deficits that have been observed in Central European economies may not be a concern, as long as they represent an optimal equilibrium adjustment induced by the real convergence phenomenon. Third, the equilibrium dynamics are characterised by a negative comovement between consumption (c_t) and hours (l_t). Under perfect competition, wealth effects brought about by the temporary productivity growth shock play a much larger role in shifting traded sector and aggregate hours down. In contrast, the positively correlated responses of c_t and l_t that characterised the baseline scenario were the result of the fall in aggregate demand induced by the countercyclical optimal policy response. Lastly, the response of real variables appears to be largely independent of the monetary policy regime in place. Even though there are certain differences between our structural model and the one developed by Ravenna and Natalucci (2008), the last implication coincides, in fact, to one of the main results in that paper. Despite this, the Ramsey planner can still bring about significant welfare gains relative to the equilibrium allocation under simple rules by setting up interest rates optimally. Essentially, these Ramsey benefits are derived from higher initial values of consumption. In order to understand the merits of implementing the optimal plan, however, it is necessary to examine the dynamics of nominal variables to which we now turn.

Flexible price adjustment in the traded sector implies that the Ramsey planner can no longer make effective use of the terms of trade externality to deflate the economy in the initial periods. Relevant to this alternative market structure is the presence of the monopolistic distortion in the nontraded sector, which implies that the steady state level

[35] Households do not face a portfolio allocation problem, as domestic bonds are in zero net supply.

of output is suboptimally low. As a result, there is a scope to adopt an expansionary policy and to inflate the economy even in the absence of shocks. Moving nontraded sector production closer to its efficient level, however, is not as straightforward as it would be in a one sector model. When labour supply is perfectly substitutable across the economy, changing the relative allocation of labour towards the nontraded sector is possible only if traded sector inflation is higher. Intuitively, such a policy erodes the purchasing power of H-type workers and triggers an expenditure switching effect towards services. To see this in a more formal way, notice that a policy aimed at correcting monopolistic distortions would necessarily have to raise the nontraded sector real marginal cost. Given the relationships in (D.2) and (D.3), which also hold under perfect competition, $mc_{N,t}$ can be written as:

$$mc_{N,t} = \frac{mc_{H,t}}{\rho_{nh,t}} = \frac{1}{\rho_{nh,t-1}\frac{\pi_{N,t}}{\pi_{H,t}}\frac{1+g^*}{1+g_{H,t}}} \tag{2.30}$$

We first consider how the Ramsey allocation is welfare improving when no convergence takes place. In that instance, there is balanced growth throughout the economy ($g_{H,t} = g^*$ for all t) and, as a result, stimulating nontraded sector production beyond the steady state level is only possible if the path of $\pi_{H,t}$ is relatively higher, on average, as compared to that of $\pi_{N,t}$. Our simulating results (not included) reveal that the annualised initial response of $\pi_{H,t}$ would be as large as 60% in the absence of shocks. Whereas such a prediction might appear unrealistic, its main theoretical purpose is to show how large the inflationary effects of optimal policy would be under perfect input mobility. On the other hand, the asymmetric real convergence shock we consider in figure 2.11 attenuates the need to inflate the traded sector. In fact, $\pi_{H,t}$ reaches just 10% in the initial period, with its transition path being persistently deflationary afterwards. Moreover, the optimal level of nominal interest rates falls from -4% (in the absence of shocks) to -1% on impact.[36] It follows that real convergence brings about a less expansionary optimal monetary policy response, whose effects on aggregate demand are more moderate.

Besides the opposite optimal movements of nominal interest rates, two striking additional differences arise with respect to the baseline case. First, the transition path of aggregate inflation mirrors that in figure 2.2a. In this sense, notice that the inflationary effects of the real convergence shock are felt only initially, as the economy experiences an 8% optimal value of π_t. However, the norm under traded sector perfect competition is to have an optimal, persistently lower transition path of inflation relative to its steady state

[36]Extending the Ramsey problem to include the zero lower bound constraint on nominal interest rates can be easily done by adopting the penalty function approach discussed in the next section. We decided not to discuss the modified problem, mainly because: (i) the ZLB constraint is no longer binding nowadays; (ii) the optimal allocation that imposes positive interest rates is basically identical to the one in figure 2.11.

value. Second, the nominal exchange rate trend implied by the model is that of an appreciation. The relative value of the domestic currency initially declines, owing to the scope for correcting the nontraded sector monopolistic distortion. This finding suggests that the textbook predictions of the Balassa-Samuelson model can be altered if the effects of asymmetric productivity growth are considered within a modern macroeconomic framework with intertemporal maximisation and nominal rigidities.

Given the striking differences in the real convergence adjustment that arise if perfect competition is allowed for, it is mandatory to check whether inflation targeting rules maintain their dominating welfare performance relative to nominal peg arrangements. As shown in table 2.3, we find that they do. The compensating variation needed to make domestic consumers indifferent between the Ramsey and the simple rule responses is, however, larger. Hence, the welfare costs associated with simple rules are augmented by as much as two orders of magnitude if real convergence generates significant jumps in domestic consumption. Building on the insights from Aoki (2001), our analysis suggests that the best performing simple rule is consistent with nontraded sector price stability.[37] Since nominal adjustment is imperfect only in this sector, we label such a policy rule as core inflation targeting. The appealing welfare properties of achieving price stability in the sticky price sector are easily discerned from figure 2.11, where we show that the transition paths of all variables are closest to the optimal outcomes.

Interest-Rate Rule	Feedback Coefficients			Conditional Welfare Cost
	$\alpha_\pi{}^*$	α_s	$\bar{S}$	($\lambda^c \times 100$)
Ramsey policy	-	-	-	0
Optimised CPI inflation targeting	10000	-	-	0.061497
Optimised core inflation targeting	10000	-	-	0.060929
Optimised nominal peg	-	700	0.9638	0.064595
Nominal peg at the initial state	-	700	1	0.065509

α_π is restricted in the [-10000,10000] interval

Table 2.3: Welfare analysis under perfect competition in the traded sector

In contrast, choosing a fixed exchange rate arrangement would make domestic consumers worse off, with an increase in λ^c equal to 0.004%. The change in the compensating variation is lower relative to the baseline case, where it had a value of 0.01%. The last finding suggests that a larger elasticity of substitution between domestic and foreign goods decreases the welfare gains that an inflation targeting regime can achieve. To enhance

[37] The inertial rule in equation (1.54) is disregarded from the sensitivity analysis, as its welfare performance was found similar to that of a CPI inflation targeting rule.

the understanding as to why a nominal peg is suboptimal, it is useful to consider the transition paths in figure 2.11. Whereas both the Ramsey and the inflation targeting plans imply expansionary interest rate responses, the movements in the policy instrument under a nominal peg are in the opposite direction. At a glance, discrepancies between the levels of domestic and foreign interest might lead one to believe that the UIP condition is violated. However, the higher values of domestic interest rates are in fact triggered by increases in the risk premium, arising from the accumulation of foreign debt. As the law of price holds for the traded good, stabilising the nominal exchange rate also induces a complete stabilisation of $\pi_{H,t}$.[38] Since traded goods are in excess supply and the rate at which their prices change is fixed, a higher path of nontraded inflation is needed to induce consumers to switch their expenditures towards the expanding sector. Hence, aggregate inflation is necessarily higher, suggesting that a fixed exchange rate regime can indeed fuel inflationary pressures in the economy. This prediction is in sharp contrast to the baseline adjustment scenario, where a mix of exchange rate stability and aggregate disinflation was implied by our analysis.

When the policy maker chooses the level of fixing S_t optimally, he does so by allowing a 3.72% degree of appreciation. The policy recommendation is consistent with our previous analysis. Specifically, if a binding institutional arrangement (such as the participation in the ERM II mechanism) obliges a country to establish a central parity at which it aims to stabilise the exchange rate, then it is generally desirable, from a welfare point of view, to choose a moderate degree of trend-implied variation for $\bar{S}$. Implementing the optimal peg arrangement also alleviates the inflationary pressures that would arise if $\bar{S} = S_{-1} = 1$, resulting in a better alignment with the Maastricht constraint on price stability (e.g. $\pi_t \leq 3.5\%$ in annualised terms). Although both policies violate the upper bound imposed on CPI inflation, the optimised peg does so only marginally. This is because the highest realisation of π_t in the first two years is equal to 3.76%. It is understood that a tradeoff between meeting the Maastricht constraints and achieving the highest welfare within the class of fixed exchange rate rules will exist in the model. Our simulation results reveal that a peg at $\bar{S} = 0.916$ would meet the constraint on price stability for a two year period. The welfare loss would increase from $\lambda^c = 0.0646\%$ to $\lambda^c = 0.0662\%$ under this alternative ERM II consistent arrangement. Finally, the reader can intuitively realise that a larger convergence shock would augment the inflationary pressures in the economy, requiring an even lower value of $\bar{S}$. The welfare loss associated with a nominal peg that satisfies the Maastricht convergence criteria would be even larger in that case.

[38]This effect can be noticed from equation (2.28).

2.6 The Maastricht Constrained Optimal Policy

The integration of the Czech Republic, Poland or Hungary within the EMU critically depends on a successful participation in the exchange rate mechanism (ERM II) for a two-year period. This constrained arrangement represents a formal examination of the new member states' ability to comply with a set of rules, commonly known as the Maastricht convergence criteria, whose purpose is to guarantee the efficiency of the common monetary policy in the union. Ignoring the regulations involving fiscal sustainability, the conditions defined in the Treaty on the Functioning of the European Union refer to:

- price stability : the change in the CPI index should not exceed an upper threshold, defined as 1.5 percentage points over the average rate of inflation in the three EMU countries with the lowest inflation rates
- exchange rate stability: fluctuations in the nominal exchange rate should not exceed a 15% deviation from a central parity established prior to joining the exchange rate mechanism
- convergence of nominal interest rates: the long-term nominal interest rate should not exceed by two-percentage points the average rate in the three member states with the best record of price stability.

Candidates willing to adopt the single currency that have a distinct macroeconomic performance with respect to the rest of EMU will not be allowed to join, as they might disrupt the decisions made by the ECB by having different priorities. Of course, even in circumstances where the candidate country is characterised by many idiosyncratic features, monetary policy may still be able to engineer adjustments plans to various shocks that comply with a given set of constraints. However, certain differences will arise with respect to the unconstrained optimal policy outcomes, as some endogenous variables are restricted within the Maastricht-defined feasible region. As the convergence criteria that need to be obeyed are often binding, the constrained optimal plan is characterised by additional welfare losses.

Given that euro adoption in Emerging Europe is likely to be contemporaneous with some form of real convergence, it is essential to study the implications of our policy analysis for the ERM II period. In this section, we examine the differences that arise in the Maastricht-constrained optimal plans and we quantify the pain of complying with the nominal convergence criteria. The tasks are conducted under the two alternative market structures previously considered and under various real convergence scenarios.

The convergence criteria associated with the ERM II add a set of inequality constraints to the nonlinear programming problem defined in Appendix E. These are represented by:

$$\pi_t - \pi_t^* \leq C_\pi \tag{2.31}$$

$$(1 - C_S)\ \bar{S} \leq S_t \tag{2.32}$$

$$S_t \leq (1 + C_S)\bar{S} \tag{2.33}$$

$$i_t - i_t^* \leq C_i \tag{2.34}$$

where the parameters associated with the nonlinear constraints are specified in order to match the time convention in our model: $C_\pi = 1.015^{0.25} - 1$; $C_S = 0.15$ and $C_i = 1.02^{0.25} - 1$. Notice that equations (2.28)-(2.31) represent simplifications of the actual convergence criteria, as the equivalence between short-term and long-term interest rates is implicitly assumed. Furthermore, the restrictions imposed on nominal variables are tighter as compared to the real-world analogues. This is because the inequality constraints have to be satisfied on a quarterly, rather than on an annual basis.

To determine the Maastricht constrained optimal allocation, we use the most common way of dealing with inequality constrained problems, namely that of a penalty function approach (discussed in Bazaraa et al., 2006; Luenberger, 2010). The idea of this class of solution methods is to approximate the difficult and computationally demanding problem at hand with an equivalent optimisation problem which involves only simple equality constraints and can be approached using standard algorithms. The conversion involves the addition of a penalty term to the objective function, which prescribes a high cost for any violation of the constraints. To briefly illustrate how the method works, consider the generic problem:

$$\begin{aligned} &\text{maximise} \quad f(x) \\ &\text{subject to} \quad h(x) \leq 0 \end{aligned} \tag{2.35}$$

where x is a vector of variables. $f(x)$ defines the objective function to be maximised and $h(x)$ represents a set of inequality constraints.

The penalty approach replaces the optimisation in (2.35) by an unconstrained problem of the form:

$$\text{maximise} \quad f(x) - \nu P(x) \tag{2.36}$$

where $P(x)$ is a function of h, whereas ν represents a sufficiently large number which measures the decline in the objective function when the inequality constraint is violated.[39] For a sequence of increasing penalty parameters $\{\nu_j\}$, the solution of the unconstrained problem convergences to the true solution from outside the feasibility set.

In choosing the functional form of $P(x)$, one has to make sure that only the values of x that do not fall in the feasible region are penalised. Based on these considerations, we choose a quadratic form defined below:

$$P(x) = \frac{1}{2}\max[0, h(x)]^2 \tag{2.37}$$

With the basic tools at hand, one can easily approximate the solution to the Maastricht constrained optimal policy problem by looking at the alternative specification defined in appendix E, in which a penalty term is added to the augmented Lagrangian. In specifying the modified problem, however, there is no need to include penalty terms that account for the violation of *all* the constraints in (2.31)-(2.34), mainly because not all the restrictions are binding. Rather than doing that, we make use of the structure of the unconstrained problem and include only the active set of constraints.

2.6.1 Monopolistic Competition in the Traded Sector

We first characterise the Maastricht constrained optimal allocation when monopolistic competition in the traded sector is assumed. Building on the results from the unrestricted Ramsey plan, the constrained solution is determined by adding a penalty for the violation of the interest rate convergence criteria. As we show in figure 2.12, the constraint is sufficient for maintaining both the nominal exchange rate and inflation rate variables within the ERM II numerical bounds. This property holds true for all the alternative real convergence scenarios previously defined in section 2.4.2. The processes followed by traded sector productivity are distinguished in figure 2.12 by the long-run relative productivity ratios ($\bar{X}$) they imply. The first two adjustments, denoted by $\bar{X} = 0.8$ and $\bar{X} = 0.9$, correspond to convergence in growth rates specification. In their case, the initial productivity growth increase is identical. Moreover, the long-run relative productivity ratios $\bar{X}$ they imply are obtained by altering persistence parameter ϱ. On the other

[39] In general, a theoretical equivalence between problems (2.35) and (2.36) can be proved only when $\nu \to \infty$. However, the eigenvalue structure of the modified Hessian matrix becomes increasingly unfavourable for high values of ν. As a result, the computational implementation of penalty methods involves a sequence of problems indexed by an increasing ν. The iterative procedure is run until some measure of convergence is achieved.

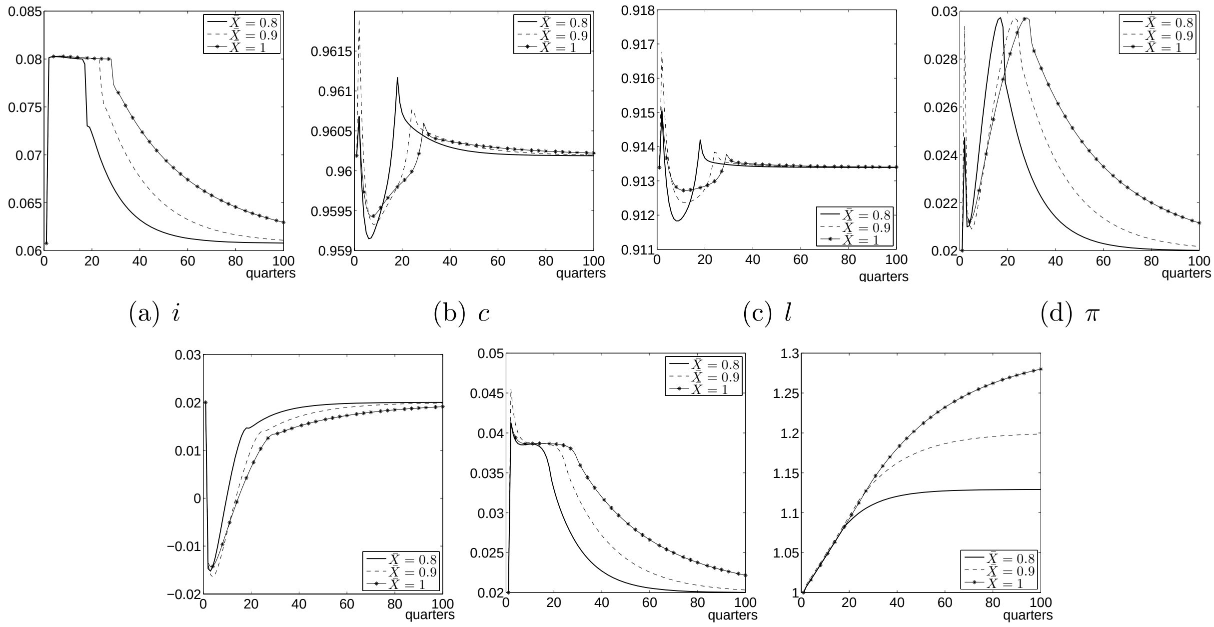
hand, the third real convergence scenario (denoted by $\bar{X} = 1$) illustrates the Maastricht constrained optimal plan when traded sector productivity fully converges in levels. As we emphasised before, the modelling approach of the full convergence scenario is different, mainly because it implies an initial productivity growth shock of a lower magnitude. Moreover, the subsequent adjustment of X_t associated with this process has a different curvature (see figure 2.9).

Whereas the previously considered interest rate path entailed a strong countercyclical response, which enabled the Ramsey planner to induce a welfare-improving short-term appreciation of the nominal exchange rate, such an adjustment is no longer possible under the Maastricht constraints. This is because the upper limit imposed on the interest rate path becomes a binding restriction. The higher the persistence of the real convergence process is, the longer the time span where the policy instrument needs to be maintained at the 8% annualised value. The number of periods varies between four and eight years, depending on how quickly the growth acceleration process is subdued. On the other hand, when the interest rate convergence criterion ceases to be a binding restriction, the unconstrained and the constrained solution imply identical dynamics in the remaining periods.

The fact that nominal interest rates are lower under the Maastricht constraints triggers a short-term expansion in aggregate demand. This effect can be noticed from the increased levels of consumption and hours following the productivity growth shock. Observe also that as long as the interest rate is fixed at the upper bound, the nominal exchange rate depreciation is similar across the three convergence scenarios. However, this trend variation is suboptimal, as domestic consumers find it less affordable to consume foreign products. In turn, the resulting negative wealth effect triggers a reduction in consumption and hours in the subsequent periods. When the endogenous responses approach the final period of the constrained adjustment, our results indicate that aggregate demand recovers. Still, as we previously emphasised, real variables' dynamics are characterised by a reduced amplitude.

The way prices respond is quite intuitive. For instance, a less countercyclical policy stance dampens the disinflationary pressures affecting traded goods. On the other hand, the nontraded sector inflation attributable to unbalanced growth is less pronounced, as $\pi_{N,t}$ is stabilised around 4% as long as the interest rate constraint is binding. When combined, these two effects trigger a complex adjustment for aggregate inflation, which oscillates between the annualised levels of 2% and 3% at irregular intervals.

Lastly, the welfare costs associated with the Maastricht constraints are illustrated in table



(a) i (b) c (c) l (d) π

(e) π_H (f) π_N (g) S

Figure 2.12: The Maastricht constrained optimal plan under monopolistic competition

2.4 , suggesting values of the compensating variation somewhat similar to those associated with the simple rules. Notice that the conditional welfare costs are not monotonic in $\bar{X}$, mainly because the full convergence adjustment is modelled through a distinctive approach (see equation 2.22) and its associated initial productivity growth shock is lower.

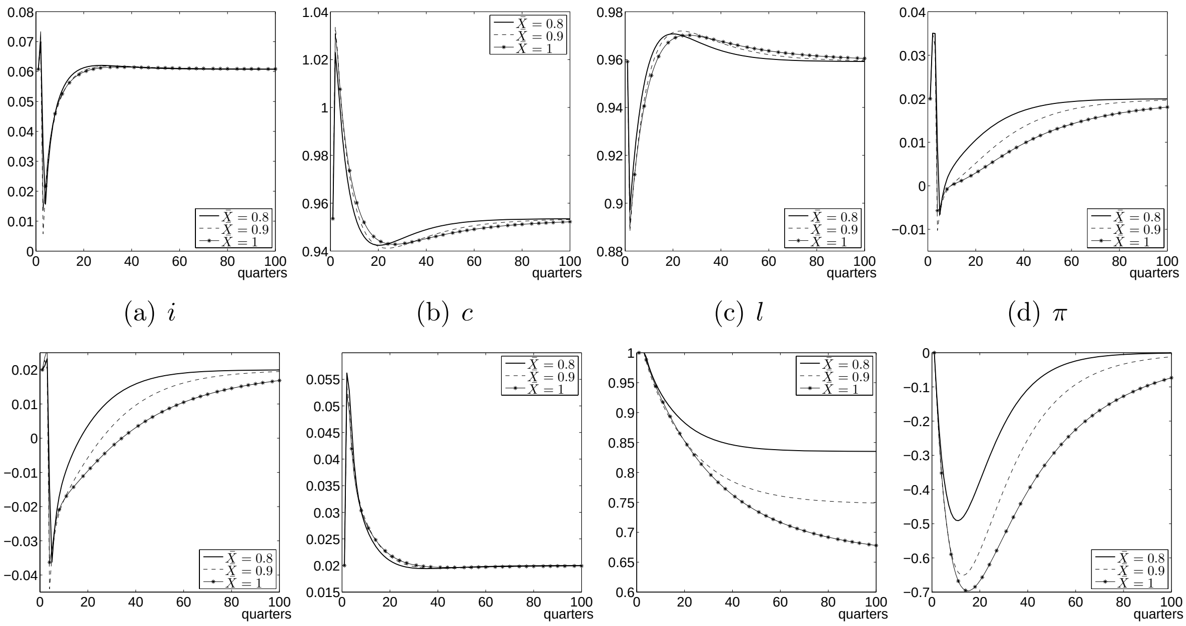
As euro adoption is likely to bring significant microeconomic benefits, the pain of adjustment required by the ERM II mechanism seems to be relatively small.

Table 2.4: The welfare costs of the Maastricht constrained optimal plan

Traded sector market structure	Conditional welfare cost ($\lambda^c \cdot 100$)		
	$\bar{X} = 0.8$	$\bar{X} = 0.9$	$\bar{X} = 1$
Monopolistic competition	0.00121	0.00197	0.00187
Perfect competition	0.00012	0.00004	0.00005

2.6.2 Perfect Competition in the Traded Sector

We now briefly consider the effects brought about by the Maastricht constraints under perfect competition. In section 2.5 it was shown that only the inflation criterion was violated in the initial period, as the CPI index increased at an annual rate of 8%. As the optimal policy response was expansionary, the constraint imposed on nominal interest rate was slack and the exchange rate variation was within the $\pm 15\%$ interval in the first two years. Based on these considerations, one should expect minimal modifications to the paths implied by the unconstrained optimal plan. Moreover, the welfare costs associated with ERM II restrictions should be small. As shown in table 2.4, we find that this is indeed the case. Specifically, the magnitude of the compensating variation is one to two times lower as compared to the monopolistically competitive case. If we previously advocated that the Maastricht constraints should not be a concern to policy makers willing to join the euro area, then the magnitude of the welfare loss suggested by our results is even more reassuring. The only additional insight brought about by



(a) i (b) c (c) l (d) π

(e) π_H (f) π_N (g) S (h) nfa

Figure 2.13: The Maastricht constrained optimal plan under perfect competition

the constrained adjustment is that, in order to keep inflation under control in the first period, interest rates should moderately increase by 1 percentage point. The reader can easily interpret the remaining transition paths along the lines suggested in section 2.5. In addition to the previous analysis, however, the responses in figure 2.13 offer additional information on how sensitive the endogenous dynamics are with respect to real convergence adjustment considered. Suggestive in this sense is the accumulation of net foreign debt, which increases quite significantly as a function of the long run relative productivity ratio $\bar{X}$.

2.7 Conclusions

This chapter has addressed some of the complex aspects of modelling the recent real convergence experience of Central European economies and its implications for the design of monetary policy and for joining the euro area. In consideration of the specific characteristics of these economies, which are small, open and have been subjected to unbalanced growth in manufacturing and services, we have developed a new theoretical model that incorporates the above stylised facts and can be used to study the conduct of monetary policy under real convergence. In relation to the previous literature, we have extended the complete markets model in Masten (2008), by allowing for trade in noncontingent bonds and examining the effects of uncorrected steady state distortions. In selecting the alternative assumptions, the study aimed to offer a more realistic account of the convergence phenomenon, by endogenising current account fluctuations. The chapter also provided a unified treatment of the Ramsey problem and the welfare costs of simple rules. The comparative approach between the inflation targeting and fixed exchange rate allocations and their relation to the optimal plan is likely to be more informative to central banks in the region, as these institutions have opted for either of the two regimes.

Notwithstanding the proven achievements of the New-Keynesian research programme, the models currently used for monetary policy analysis rely on two assumptions that are often taken for granted. One is the balanced growth path property, which has generally been an accurate description of the US and other advanced economies. The other assumption concerns the small volatility of shocks that enable the researcher to approximate the solution of the original model locally. In the past decade, however, emerging economies such as China, Brazil, the Czech Republic or Poland have experienced persistent growth rates of GDP per capita that have been well above the corresponding levels in the United States or the euro area. The prominent role that permanent shocks have in these economies, with consumption being more volatile than output, has been emphasised by Aguiar and Gopinath (2007), who noted that "shocks to trend growth - rather than transitory fluctuations around a stable trend - are the primary source of fluctuations in emerging markets." It is clear that in order to capture the specific characteristics of emerging economies, which often display trends in relative prices or real variables such as the current account, the standard tools available for explaining economic phenomena have to be adapted.

For instance, models have to be specified in terms of nonstationary variables to enable a simultaneous study of growth and fluctuations. Moreover, the class of models that allow for a transparent mapping between the nonstationary and stationary representations of the dynamic system might be severely restricted. As a result, the researcher has to undertake the additional task of choosing a theoretical framework and its underlying assumptions under which such a transformation is feasible. Otherwise, an analysis of temporary shifts in the growth rate and how monetary policy should be conducted in response to such shocks will not be possible.

In rich open economy models with imperfect risk sharing, further complications can arise because the Pareto optimal allocation is not tractable. The analysis of transitory shifts to the growth rate would work as usual if shocks affecting it have a small variance. In that instance, one can still operate with a stochastic specification of the detrended dynamic system, by approximating the true solution up to a first or second order degree of accuracy. However, when shocks to the growth rate are large, local methods are appropriate only if a nonstationary solution to the social planner's problem is available and the sticky price allocation can be expressed in terms of deviations from that efficient allocation. The essential distinction between the perfect risk sharing model in Masten (2008) and the one developed here refers to the extent to which such a representation is possible. It follows that the solution of a stochastic version of our framework would have required the use of projection methods, although their implementation would have been very difficult. For all these complications brought about by the incomplete markets assumption, we have justified why a perfect foresight, nonlinear solution method was indeed the only tool that was appropriate.

In relation to the optimal monetary policy stance under real convergence, the analysis has shown that the policy recommendations depend on the degree of substitutability between domestic and foreign goods and the market structure in the open sector. These assumptions, in turn, shaped the nominal exchange rate trend predicted by the model and the direction of adjustment in the policy instrument.

The baseline case examined the Ramsey problem under monopolistic competition. Owing to the presence of the terms of trade externality, which dominated the incentives to inflate the economy arising from the distorted steady state, the optimal interest rate response was countercyclical. The merits of such a policy were to induce a temporary appreciation of the nominal exchange rate, thereby making foreign goods relatively cheaper. As a result, detrended consumption and hours decreased and the welfare benefits of working less outweighed the negative effects of lower consumption. Our analysis also suggested that the financial market structure is largely irrelevant when the elasticity of substitution between domestic and foreign goods is equal to unity. Among the class of interest rate rules considered, the welfare costs we quantified in terms of the detrended consumption compensating variation were relatively large when a nominal exchange rate peg is implemented.

The appealing welfare properties of inflation targeting regimes were confirmed in the second adjustment scenario, which studied the effects of perfect competition in the traded sector. In the alternative setup, the wealth effects triggered by the productivity growth shock induced more substantial jumps in domestic consumption, resulting in significant borrowing from abroad. Our analysis suggested that when the effects of permanent shocks feed through to domestic consumption, the welfare costs of simple rules are substantially larger. Among these, a core inflation targeting regime that stabilised nontraded inflation performed best. The different market structure also offset the steady state distortions in the traded sector, the terms of trade externality and implied a downward trend in relative prices. Because of these modifications, the optimal interest rate response was found to be procyclical, although less so than in the absence of shocks.

Our work has emphasised the complex relationship between nominal and real convergence, which was contingent not only on the monetary regime in place, but also on the adjustment scenario considered. When monopolistic competition in the traded sector was assumed, the optimal plan was associated with persistent positive deviations of CPI inflation from its steady state value. Whereas a higher price level was also triggered by the optimised inflation targeting rule, the opposite held true when a nominal peg was in place. Hence, the concern that a fixed exchange rate regime fuels inflationary pressures in the economy might not always be legitimate. In contrast, the above predictions were reversed under perfect competition, where a nominal peg gave rise to positive price changes.

This chapter has also discussed the tension between real convergence and the Maastricht constraints, contingent on the monetary policy regime in place. An additional contribution was to derive the welfare maximising choice of a central parity during the ERM II mechanism, by showing that moderate levels of trend implied variation are optimal for fixing the nominal exchange rate. Lastly, the welfare costs associated with Maastricht constrained optimal plan were quantified. In this respect, the analysis suggested that the pain of complying with the nominal convergence criteria under real convergence is likely to be small.

Chapter 3

A Structural Comparison between the Czech Republic and the Euro Area

> "The one-size fits all monetary policy corset (...) is most costly to a member state if it is subject to especially severe asymmetric shocks or if its structure is such as to cause even symmetric or common shocks to have seriously asymmetric impacts on employment and output."
>
> Buiter (2000)

Are Central European economies prepared to join the euro area? According to the Optimum Currency Areas literature[1], potential members of a currency union should be less preoccupied about losing the benefits of monetary autonomy when: (i) prices and wages are sufficiently flexible; (ii) there is a high degree of international factor mobility and (iii) the likelihood of asymmetric shocks across the monetary union is low (Corsetti, 2008; Mongelli et al., 2005).[2] Due to the substantial evidence on the low degree of international labour mobility and the empirical relevance of nominal rigidities, the monetary integration decision should be mainly contingent on the business cycle synchronisation between prospective and actual members of the currency area. The existence of structural asymmetries within the EMU implies that the policy choices made by the ECB can be less suitable to some economies. The smaller the euroland member is, the higher the macroeconomic costs of being structurally different are. Moreover, a low degree of business cycle correlation means that coping with the euro area interest rates on a permanent basis is likely to be more painful. Hence, for quantifying the costs of monetary integration, it is important to understand if the sources of EMU macroeconomic fluctuations and their transmission mechanisms are likely to be compatible with those in Emerging Europe.

The business cycle synchronisation between two economies can be perceived as an alternative measure of real convergence (Frankel, 2005), which complements the narrowing productivity gap definition we used in the first two chapters. Both notions are essential

[1] The classic contribution is Mundell (1961). Modern reconsiderations of the original theory, which use dynamic micro-founded models, have been recently surveyed by Tavlas (2007). See also Dellas and Tavlas (2009) and Corsetti (2008).

[2] Other criteria commonly used include the degrees of openness, trade integration and cross border risk sharing.

determinants of the monetary integration decision, although they play different roles in the assessment. Whereas a converging level of GDP per capita may hinder the transition towards the single currency area, for it implies welfare losses induced by the need to comply with the Maastricht criteria, the degree of structural convergence determines whether delegating monetary authority to the ECB is appropriate. By exploring the second definition of real convergence, the complementary work conducted in this chapter studies the extent upon which euro adoption in the Czech Republic is desirable in the long-run. In pursuing the above goal, the research seeks to identify the extent to which structural convergence has been achieved by the emerging European economy and whether its business cycle has become aligned with that of the monetary union. A rigorous identification of the sources of structural heterogeneity is of clear interest to policy makers, as it enables them to foresee the circumstances when the stabilisation outcome of a common monetary policy might be imperfect.

To evaluate the long-run effects of monetary integration, we develop a novel small open economy model that takes the euro area levels of output, inflation and interest rates as exogenous processes. While building on the work by Kollmann (2001), the core structure of the model incorporates a large numbers of shocks and frictions that have been recently shown to provide a very good fit in empirical work. The resulting theoretical representation of the economy is estimated using Bayesian techniques for two datasets, one for the Czech Republic and one for Austria. Hence, the structural comparison we make relative to the EMU is based on an indirect approach, which treats Austria as a representative economy for the whole region. Of course, for such an assumption to be adequate, Austria needs to be a well integrated economy in the euro area, which has a high degree of business cycle synchronisation with the rest of the monetary union and a similar macroeconomic adjustment with respect to different shocks. The recent papers by Furceri and Karras (2008) and Giannone et al. (2010) provide comprehensive evidence to validate the above view. A very important advantage of our approach is that the same macroeconometric model is used throughout the analysis. As a result, we are able to focus solely on data driven, rather than model driven, structural differences between the two economies. To evaluate the latter, our aim is not only to compare the values of deep macroeconomic parameters, but also to study their effects on theoretical objects such as impulse response functions and variance decompositions. The use of such diagnoses for assessing the optimality of currency areas has become increasingly popular following the influential work by Bayoumi and Eichengreen (1993).

The transition from the “catch-up” to the “business cycle synchronisation” component of real convergence is accompanied by a change in the modelling approach that needs to be emphasised. Through its distinct empirical focus, Chapter 3 examines the cross-country evidence on the incidence and volatility of macroeconomic shocks and studies how various frictions affect the way policy decisions are transmitted throughout the economy. Given that a stochastic environment is needed to address the above topics, our work considers a comparative structural analysis of the Czech Republic and the euro area once the growth acceleration process has come to an end. As a result, local approximation methods become legitimate and business cycles are isolated along a constant, long-run trend.

The eastern expansion of the European Union has stimulated an increasing amount of research dedicated to the study of business cycles in Central European economies. Some authors (Angeloni et al., 2007; Benczúr and Rátfai, 2010) simply documented the stylised facts of macroeconomic fluctuations in the region. Their papers showed that business cycles in Central European economies share many common features with those in other emerging markets, mostly because of the increased volatility of variables such as consumption and output. Fidrmuc and Korhonen (2003), Süppel (2003), Frenkel and Nickel (2005) and García-Solanes and María-Dolores (2008) employed the SVAR methodology to identify demand and supply shocks and their degree of correlation with the corresponding fluctuations in the euro area. In spite of revealing a generally low degree of business cycle synchronisation, these studies found that the heterogeneity between the euro area and the CEEC region has declined over time (Frenkel and Nickel, 2005). A different side of the story is told by Jarociński (2010), who compares the transmission mechanism of monetary policy shocks between Eastern and Western members of the European Union. Using a Bayesian SVAR approach with hierarchical priors, Jarocinski observes that "in spite of the structural differences between the regions, the impulse responses of output and prices to monetary policy shocks are similar in the new member states and in the euro area countries."[3] All these empirical facts will serve as an informative point of reference when relating our results to the previous literature.

Although useful to a certain extent, the SVAR methodology has been criticised for its lack of theoretical structure which creates difficulties in mapping a set of VAR innovations into some meaningful economic shocks. In addition, these procedures are often characterised by a certain degree of subjectivity involved in choosing the number of variables to be included in the VAR and deciding upon an adequate identification strategy. As Fernández-Villaverde et al. (2007) and Chari et al. (2004) observe, the list of potential methodological shortcomings is vast. For example, an economic theory might postulate a different number of relevant shocks than the number of shocks included in the VAR. Another reason for

[3] Qualitative similarities of the conditional responses to a monetary policy innovation are also suggested by Anzuini and Levy (2007) in an earlier paper. Borys et al. (2009) conclude that the Czech transmission mechanism of monetary policy shocks is well functioning, being similar to the one in the euro area. Their results are robust with respect to the four different Bayesian and classical estimation methods they use.

concern about these studies is related to the common invertibility problem, which is caused by the impossibility to express economic shocks as linear combinations of current and past VAR innovations.[4]

In the context of the European monetary integration process, we feel that a more promising avenue for analysing the business cycle synchronisation across countries is to adopt a Bayesian approach. The system-based estimation technique allows the researcher to evaluate the empirical fit of a theoretical DSGE model, by maximising the likelihood function generated by the latter. While embedding the desirable optimisation behaviour by agents, the microfounded structure permits a transparent identification of the shocks, their transmission mechanisms and the effects of policy decisions on the economy. This represents an advantage over the less rigorous identification of shocks characterising the SVAR methodology. It should be noted, however, that imposing a complete multivariate representation on the data, given by the approximated solution to a DSGE model, is not a trivial task. This is because the estimation exercise has to generally cope with a large number of frictions and shocks, and to derive the marginal posterior distribution of a large set of parameters.

The macroeconometrics literature employing Bayesian techniques has advanced at a rapid pace recently, following the initial contributions by Schorfheide (2000) and Otrok (2001). In an excellent review of the current state of the art, An and Schorfheide (2007) recognise that Bayesian methods are emerging as valuable tools for forecasting and quantitative policy evaluations in macroeconomics.[5] An extensive amount of research follows the tradition established by Smets and Wouters (2003), who showed that the medium-scale model of Christiano et al. (2005) can provide a very good fit to the euro area data. Subsequent contributions were mainly developed as variants of these canonical DSGE frameworks and incorporated a large number of frictions, such as habits in consumption, investment adjustment costs, variable capital utilisation or staggered nominal adjustment with partial indexation in both the labour and goods markets. All these factors are necessary in order to induce sufficient persistence in the propagation of shocks and to match the observed impulse responses of key macroeconomic variables.

Bayesian methods have been applied to an increasing number of topics in open-economy macroeconomics. To give just a few examples, Lubik and Schorfheide (2005) estimate a structural two-country model using US and euro area data, whose purpose is to evaluate the importance of nominal rigidities, the transmission of monetary policy shocks and the determinants of real exchange rate fluctuations. In a small open economy model based

[4]See Fernández-Villaverde et al. (2007).

[5]See Canova (2007) for a textbook presentation.

on Gali and Monacelli (2005), the same authors (Lubik and Schorfheide, 2007) perform posterior odds tests to check whether exchange-rate targeting is a relevant characteristic of the monetary policy conduct in Australia, New Zealand and the UK. Rabanal (2009) uses a DSGE model of a currency area to explain the sources of inflation differentials between Spain and the rest of the monetary union. Finally, Justiniano and Preston (2010a) study the extent to which an estimated SOE model can account for the empirically documented influence of foreign US shocks on Canadian business cycles.

Our focus will be on a smaller class of this literature that is primarily concerned with the cross-country comparison of macroeconomic structures and business cycle correlations. In terms of its empirical purpose, this chapter relates to the work by Smets and Wouters (2005), who found a considerable degree of similarity between the types of shocks driving the US and euro area business cycles. Their analysis, however, has not been fully able to identify which structural differences have been responsible for the asynchronous fluctuations in the two economies. In contrast to Smets and Wouters (2005), Christiano et al. (2008) indicate based on a DSGE model with financial frictions a considerable degree of heterogeneity between the same economies, which refers to both the sources of fluctuations and the structural differences (i.e. the degree of nominal inertia).

More closely related to our research objectives are two recent studies that applied Bayesian methods in the context of the European monetary integration process. On the one hand, DiCecio and Nelson (2010) ask how capable the UK economy is in coping with the interest rates set by the ECB on a permanent basis. Derived within a two-country structural model, the results of this paper reveal a considerable degree of asymmetry in the real shocks hitting the UK and euro area economies. For instance, DiCecio and Nelson (2010) obtain a very low estimate of the cross-country correlation coefficients of both productivity and government spending shocks. On the other hand, Söderström (2010) revisits the prospective single currency area membership of Sweden through the lenses of an incomplete markets small open economy model. As opposed to the findings by DiCecio and Nelson (2010), the policy prescription regarding the monetary integration decision is more favourable in this case.

Although Central European economies are formally required to complete the monetary integration process, it is surprising to observe that few structural analyses were carried out in the region relative to the euro area. The only exception we are aware of is Kolasa (2009), who developed a two-country, two-sector extension of the Smets and Wouters (2003) framework. Using data for the euro area and Poland, Kolasa finds a large degree of cross-region heterogeneity that encompasses both the synchronisation and the volatility of shocks. Since such exercises are essential for quantifying the costs of a prospective EMU entry, we believe that conducting (Bayesian) structural macroeconomic comparisons in Central Europe should be a fruitful area for more extensive research.

This chapter intends to continue the recent developments in the area of Bayesian macroeconometrics, by bringing several contributions. First of all, it develops a novel small open-economy model whose core structure is inspired from the work by Kollmann (2001). The choice made for the multivariate representation of the data is not arbitrary, however. Since both Laxton and Pesenti (2003) and Ravenna and Natalucci (2008) argued that a reasonable framework aiming to explain fluctuations in the Czech Republic should account for the fact that bilateral trade is carried out mostly in the intermediate goods sector, we see this assumption underlying Kollmann's model as a promising avenue to explain the data. Relative to the original framework which is calibrated, rather than estimated, we augment its shock structure and enrich the dynamics by incorporating external habit formation and partial indexation in the Calvo-type nominal adjustment rules for prices and wages.

The second contribution is conceptual. In contrast to Smets and Wouters (2005) and Kolasa (2009), who approached the topic using either closed-economy comparisons or two-country models, our empirical exercise is carried out by contrasting the results obtained from fitting a small open economy model to a current and a future member of the Economic and Monetary Union.

Finally, this is the first study that uses a macroeconometric model to examine Czech and Austrian business cycle fluctuations during the 1996-2011 period. The analysis is able to identify the shocks that have been responsible for the macroeconomic developments in Central Europe following the introduction of the single currency. Moreover, our paper proposes a DSGE framework that can be used for understanding the business cycle characteristics of European emerging economies in relation to their more advanced neighbours.

3.1 The Model

In this section, we derive a stochastic small open economy model to be estimated using Czech and Austrian data.

3.1.1 Households

The economy is populated by a continuum of households, indexed by j. Keeping track of each individual household is important, as we will allow for differentiated labour types and imperfect wage adjustment à la Calvo. In the presence of the above heterogeneity, each individual household will have market power and therefore will be able to charge its own differentiated wage. The individual consumer maximises expected lifetime utility, characterised by additive and separable preferences in consumption and hours:

$$E_0 \sum_{t=0}^{\infty} \beta^t \varpi_t \left[\frac{(C_{jt} - H_t)^{1-\sigma}}{1-\sigma} - \varsigma_t \frac{L_{jt}^{1+\eta}}{1+\eta} \right] \tag{3.1}$$

where σ denote the coefficient of relative risk aversion, while $\frac{1}{\eta}$ is the elasticity of labour supply with respect to the real wage.

In specifying the above functional form, we allow for external habit formation, an assumption that has become common in the empirical DSGE literature (see Justiniano and Preston, 2010a; Smets and Wouters, 2003). Its purpose is to improve the model's performance in matching the inertial response of consumption to various shocks. Habits are included in the preference structure through the term $H_t = \gamma C_{jt-1}$, which is proportional to past consumption and taken as given in the optimisation problem. $\gamma \in [0, 1]$ represents the degree of external habit persistence.

The period utility function also includes two preference shocks, denoted by ϖ_t and ς_t. The former works as a demand shock, for it generates temporary shifts in the discount factor. Consequently, it affects the intertemporal substitution of variables such as consumption. The second shock (ς_t) introduces a wedge in the intratemporal relationship between consumption and labour.

We assume the following exogenous processes for the two disturbances:

$$\ln \varpi_t = \rho_\varpi \ln \varpi_{t-1} + \sigma_\varpi \varepsilon_{\varpi,t} \ , \qquad \varepsilon_{\varpi,t} \sim \mathbb{N}(0,1) \tag{3.2}$$

$$\ln \varsigma_t = \rho_\varsigma \ln \varsigma_{t-1} + \sigma_\varsigma \varepsilon_{\varsigma,t} \ , \qquad \varepsilon_{\varsigma,t} \sim \mathbb{N}(0,1) \tag{3.3}$$

Asset Market Structure and the Flow Budget Constraint

Risk sharing is complete across domestic households, who are able to perfectly insure against fluctuations in their wealth. In contrast, agents achieve limited cross-country insurance at the international level by holding one-period foreign bonds. To deal with the potential indeterminacy caused by the net foreign assets position, we introduce an exogenous, convex risk premium term Ω, which will insure that foreign bond holdings return to their steady state value following a temporary shock. Similar considerations were also followed in the first chapter. In the above incomplete markets environment, the consumption-savings decision of the j'th household will depend on the budget constraint:

$$C_{jt} + I_{jt} + \frac{B_{jt}^H}{P_t R_t} + \frac{S_t B_{jt}^F}{P_t R_t^* \Omega(\frac{S_t B_t^F}{P_t})} = \frac{B_{jt-1}^H}{P_t} + \frac{S_t B_{jt-1}^F}{P_t} + w_{jt} L_{jt} + r_t^k K_{jt} + \frac{\Pi_{jt}}{P_t} \tag{3.4}$$

Households use their period income to finance purchases of consumption (C_{jt}), investment (I_{jt}) and bonds. To do so, households derive their income from supplying capital and labour services at the rates r_t^k and w_{jt}, from the redistribution of nominal profits Π_{jt} and from the principal payments on recently matured bonds. All these sources of income appear on the right hand side of equation (3.4). Note that while the capital stock is supplied in economy-wide perfectly competitive markets, the labour good is differentiated, allowing for market power and wage setting behaviour. Moreover, in the presence of the Calvo type nominal inertia we will introduce shortly, the model will allow for a distribution of wages across individuals. The above heterogeneity explains why an additional j index has been attached to the real wage rate.

Financial wealth is stored in the form of domestic and foreign one-period nominal bonds, denoted by B_{jt}^H and B_{jt}^F. Real purchases of the two zero-coupon securities are made at the beginning of period t at a yield equal to the domestic and foreign interest rates set by policy makers. In the case of foreign bonds, the return is adjusted by the risk premium term Ω, whose functional form is chosen as in Adolfson et al. (2007): $\ln \Omega = -\xi \left(\frac{S_t B_t^F}{P_t} - \bar{b} \right) + \omega_t$, and includes a shock to the risk premium denoted by ω_t.

$$\omega_t = \rho_\omega \omega_{t-1} + \sigma_\omega \varepsilon_{\omega,t} \ , \qquad \varepsilon_{\omega,t} \sim \mathbb{N}(0,1) \tag{3.5}$$

Capital Accumulation

We assume that all firms and the capital stock are owned by domestic residents. The accumulation of physical capital is subject to quadratic adjustment costs, as in Tobin's q model of investment. Following the benchmark models of Christiano et al. (2005), Smets and Wouters (2003) and Adolfson et al. (2007), the deadweight loss incurred by each household when increasing K_t is proportional to changes in investment, rather than to changes in the capital stock.

$$K_{jt+1} = (1-\delta)K_{jt} + \varkappa_t \left[1 - \Upsilon\left(\frac{I_{jt}}{I_{jt-1}}\right)\right] I_{jt} \tag{3.6}$$

where $0 < \delta < 1$ is the depreciation rate of capital and the adjustment cost function is defined as : $\Upsilon\left(\frac{I_{jt}}{I_{jt-1}}\right) = \frac{\kappa}{2}\left(\frac{I_{jt}}{I_{jt-1}} - 1\right)^2$, with $\kappa \geq 0$. The dynamic equation also features a stationary investment specific technological shock $\varkappa_t$, that follows a Gaussian autoregressive process:

$$\ln \varkappa_t = \rho_\varkappa \ln \varkappa_{t-1} + \sigma_\varkappa \varepsilon_{\varkappa,t} \ , \qquad \varepsilon_{\varkappa,t} \sim \mathbb{N}(0,1) \tag{3.7}$$

Wage Setting

The labour market is characterised by two dimensions of heterogeneity. On the one hand, each household supplies a differentiated labour type, indexed by j. A centralised union combines the continuum of services supplied by households into an aggregate homogeneous bundle, that is hired in competitive markets by firms:

$$L_t^d = \left(\int_0^1 L_{jt}^{\frac{\varphi-1}{\varphi}} dj\right)^{\frac{\varphi}{\varphi-1}} \tag{3.8}$$

where $\varphi > 1$ denotes the elasticity of substitution among two different labour types.

By minimising the cost of supplying one unit of the aggregate bundle, subject to the aggregation technology in (3.8), the union's demand for each labour type can be determined as:

$$L_{jt} = \left(\frac{w_{jt}}{w_t}\right)^{-\varphi} L_t^d \tag{3.9}$$

where $w_t = \left(\int_0^1 w_{jt}^{1-\varphi} dj\right)^{\frac{1}{1-\varphi}}$ represents the cost of hiring the homogeneous labour good. Note that the factor demand functions are specified in terms of the real wages $w_{jt} = \frac{W_{jt}}{P_t}$ and $w_t = \frac{W_t}{P_t}$.

In deriving the above results, it was implicitly assumed that the individual wage setting decision has no effect on the aggregate wage index w_t or on the aggregate labour demand. By setting the cost of labour type j, a monopoly supplier stands ready to supply as many hours of work as needed in order to meet the demand by firms at that particular wage.

Integrating over the continuum of households, we can obtain an expression for the total number of hours allocated to the different labour markets:

$$L_t = \int_0^1 L_{jt}\, dj = L_t^d \int_0^1 \left(\frac{w_{jt}}{w_t}\right)^{-\varphi} dj \tag{3.10}$$

On the other hand, the wage setting decision is imperfect, being subject to a Calvo-type adjustment rule. In this distorted environment, a nominal wage contract characterising the labour supply of household j is renegotiated at the optimal level with probability $1-\psi_w$, which is independent of the time period when the last adjustment took place (as in Christiano et al., 2005; Erceg et al., 2000; Smets and Wouters, 2003). In line with the recent DSGE literature, wages that are not adjusted in the current period evolve according to a past inflation partial indexation rule, governed by the parameter $\chi_w \in [0,1]$.

$$w_{jt} = \frac{\pi_{t-1}^{\chi_w}}{\pi_t} w_{jt-1} \tag{3.11}$$

The optimal Calvo wage maximises expected lifetime utility, conditionally on the wage contract being in place in the future. The maximisation problem is done with respect to the conditional labour demand curve and the intertemporal budget constraint:

$$\max_{w_{jt}} E_t \sum_{s=0}^{\infty} (\beta\psi_w)^s \left\{ \varpi_{t+s} \left[\frac{(C_{jt+s} - H_{t+s})^{1-\sigma}}{1-\sigma} - \frac{\varsigma_{t+s} L_{jt+s}^{1+\eta}}{1+\eta} \right] \right\}$$

$$\text{subject to : } L_{jt+s} = \left(\prod_{k=1}^{s} \frac{\pi_{t+k-1}^{\chi_w}}{\pi_{t+k}} \frac{w_{jt}}{w_{t+s}} \right)^{-\varphi} L_{t+s}^d$$

$$C_{jt+s} + I_{jt+s} + \frac{B_{jt+s}^H}{P_{t+s} R_{t+s}} + \frac{S_{t+s} B_{jt+s}^F}{P_{t+s} R_{t+s}^* \Omega(\frac{S_{t+s} B_{jt+s}^F}{P_{t+s}})} =$$

$$\frac{B_{jt+s-1}^H}{P_{t+s}} + \frac{S_{t+s} B_{jt+s-1}^F}{P_{t+s}} + \prod_{k=1}^{s} \frac{\pi_{t+k-1}^{\chi_w}}{\pi_{t+k}} w_{jt} L_{jt+s} + r_{t+s} K_{jt+s} + \frac{\Pi_{jt+s}}{P_{t+s}}$$

A direct consequence of perfect risk pooling of income shocks at the domestic level is that all households optimising their nominal wage in the current period will face an identical problem.[6] For this reason, we can denote the optimal choice of the wage rate by $\tilde{w}_t$, without the need to index it further by j. The variable satisfies the first order condition:

$$E_t \sum_{s=0}^{\infty} (\beta\psi_w)^s \left[\lambda_{t+s} \left[\prod_{k=1}^{s} \frac{\pi_{t+k-1}^{\chi_w}}{\pi_{t+k}} \right]^{1-\varphi} (1-\varphi) \left(\frac{\tilde{w}_t}{w_{t+s}} \right)^{-\varphi} L_{t+s}^d + \varpi_{t+s} \varsigma_{t+s} \varphi \left[\prod_{k=1}^{s} \frac{\pi_{t+k-1}}{\pi_{t+k}} \frac{\tilde{w}_t}{w_{t+s}} \right]^{-\varphi(1+\eta)} \frac{(L_{t+s}^d)^{1+\eta}}{\tilde{w}_t} \right] = 0$$

[6] As Fernández-Villaverde (2010) and Galí (2008) note, under complete markets and an additive, separable utility function, the consumption stream chosen by the household will be independent of the wage history. Another consequence of this setup is that the marginal utility of consumption (λ_t) will be equalised across households in all states and periods.

which can be more conveniently arranged as:

$$
\begin{aligned}
&\frac{\varphi-1}{\varphi}\tilde{w}_t E_t \sum_{s=0}^{\infty}(\beta\psi_w)^s \lambda_{t+s}\left[\prod_{k=1}^{s}\frac{\pi_{t+k-1}^{\chi_w}}{\pi_{t+k}}\right]^{1-\varphi}\left(\frac{\tilde{w}_t}{w_{t+s}}\right)^{-\varphi} L_{t+s}^d \\
&= E_t \sum_{s=0}^{\infty}(\beta\psi_w)^s \varpi_{t+s}\varsigma_{t+s}\left[\prod_{k=1}^{s}\frac{\pi_{t+k-1}}{\pi_{t+k}}\frac{\tilde{w}_t}{w_{t+s}}\right]^{-\varphi(1+\eta)}(L_{t+s}^d)^{1+\eta}
\end{aligned}
\tag{3.12}
$$

If wages are fully flexible ($\psi_w = 0$), equation (3.12) collapses to a standard condition expressing the real wage as a markup over the marginal rate of substitution between consumption and hours.

Following the methodology introduced by Schmitt-Grohé and Uribe (2004), it is convenient to write the wage setting condition in recursive form. To this end, we define:

$$
\begin{aligned}
x_t^1 &= \tilde{w}_t E_t \sum_{s=0}^{\infty}(\beta\psi_w)^s \lambda_{t+s}\left[\prod_{k=1}^{s}\frac{\pi_{t+k-1}^{\chi_w}}{\pi_{t+k}}\right]^{1-\varphi}\left(\frac{\tilde{w}_t}{w_{t+s}}\right)^{-\varphi} L_{t+s}^d \\
x_t^2 &= E_t \sum_{s=0}^{\infty}(\beta\psi_w)^s \left(\varpi_{t+s}\varsigma_{t+s}\left[\prod_{k=1}^{s}\frac{\pi_{t+k-1}}{\pi_{t+k}}\frac{\tilde{w}_t}{w_{t+s}}\right]^{-\varphi(1+\eta)}(L_{t+s}^d)^{1+\eta}\right)
\end{aligned}
$$

and formulate equation (3.12) as:

$$
\frac{\varphi-1}{\varphi}x_t^1 = x_t^2 \tag{3.13}
$$

The recursive expressions of x_t^1 and x_t^2 are obtained as follows:

$$
\begin{aligned}
x_t^1 &= \tilde{w}_t^{1-\varphi} w_t^{\varphi}\lambda_t L_t^d + \tilde{w}_t E_t \sum_{s=1}^{\infty}(\beta\psi_w)^s \lambda_{t+s}\left[\prod_{k=1}^{s}\frac{\pi_{t+k-1}^{\chi_w}}{\pi_{t+k}}\right]^{1-\varphi}\left(\frac{\tilde{w}_t}{w_{t+s}}\right)^{-\varphi} L_{t+s}^d \\
&= \tilde{w}_t^{1-\varphi} w_t^{\varphi}\lambda_t L_t^d + \beta\psi_w E_t\left[\left(\frac{\pi_t^{\chi_w}}{\pi_{t+1}}\right)^{1-\varphi}\left(\frac{\tilde{w}_t}{\tilde{w}_{t+1}}\right)^{1-\varphi} x_{t+1}^1\right]
\end{aligned}
\tag{3.14}
$$

Similarly:

$$
x_t^2 = \varpi_t\varsigma_t\left(\frac{\tilde{w}_t}{w_t}\right)^{-\varphi(1+\eta)}(L_t^d)^{1+\eta} + \beta\psi_w E_t\left[\left(\frac{\pi_t^{\chi_w}}{\pi_{t+1}}\right)^{-\varphi(1+\eta)}\left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t}\right)^{\varphi(1+\eta)} x_{t+1}^2\right] \tag{3.15}
$$

Given the assumed wage setting structure, the aggregate index w_t is equal to a probability weighted average of the wage rates chosen by the households able and not able to adjust in the current period:

$$
w_t^{1-\varphi} = \psi_w\left(\frac{\pi_{t-1}^{\chi_w}}{\pi_t}\right)^{1-\varphi} w_{t-1}^{1-\varphi} + (1-\psi_w)\tilde{w}_t^{1-\varphi} \tag{3.16}
$$

First Order Conditions

The assumptions of additive-separable preferences and complete markets enabled us to discuss the wage setting problem separately. We now return to the household optimisation and derive the first order conditions with respect to $C_{jt}, I_{jt}, B_{jt}^H, B_{jt}^F$ and K_{jt+1}. To this end, we define the Lagrangian associated to the maximisation problem that takes into account the objective function in (3.1) and the period constraints represented by equations (3.4) and (3.6).

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\begin{array}{c} \varpi_t \left[\dfrac{(C_{jt} - H_t)^{1-\sigma}}{1-\sigma} - \varsigma_t \dfrac{L_{jt}^{1+\eta}}{1+\eta} \right] \\ -\lambda_t \left(\begin{array}{c} C_{jt} + I_{jt} + \dfrac{B_{jt}^H}{P_t R_t} + \dfrac{S_t B_{jt}^F}{P_t R_t^* \Omega(\frac{S_t B_t^F}{P_t})} \\ - \dfrac{B_{jt-1}^H}{P_t} - \dfrac{S_t B_{jt-1}^F}{P_t} - w_{jt} L_{jt} - r_t^k K_{jt} - \dfrac{\Pi_{jt}}{P_t} \end{array} \right) \\ -Q_t \left[K_{jt+1} - (1-\delta) K_{jt} - \varkappa_t \left[1 - \Upsilon\left(\dfrac{I_{jt}}{I_{jt-1}} \right) \right] I_{jt} \right] \end{array} \right]$$

where λ_t and Q_t represent the Lagrangian multipliers attached to the intertemporal budget constraint and the capital accumulation equation respectively. The optimal plan of the endogenous variables must satisfy:

$$\lambda_t = \varpi_t (C_{jt} - H_t)^{-\sigma} \tag{3.17}$$

$$\lambda_t = \beta E_t \left[\lambda_{t+1} \frac{R_t}{\pi_{t+1}} \right] \tag{3.18}$$

$$E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{\pi_{t+1}} \left(R_t^* \Omega() \frac{S_{t+1}}{S_t} - R_t \right) \right] = 0 \tag{3.19}$$

$$-\lambda_t + Q_t \varkappa_t \left[1 - \Upsilon\left(\frac{I_{jt}}{I_{jt-1}} \right) - \left(\frac{I_{jt}}{I_{jt-1}} \right) \Upsilon'\left(\frac{I_{jt}}{I_{jt-1}} \right) \right] + \beta E_t \left[Q_{t+1} \varkappa_{t+1} \Upsilon'\left(\frac{I_{jt+1}}{I_{jt}} \right) \right] \left(\frac{I_{jt+1}}{I_{jt}} \right)^2 = 0$$

$$Q_t = \beta E_t \left[(1-\delta) Q_{t+1} + \lambda_{t+1} r_{t+1}^k \right]$$

together with the transversality conditions $\lim_{t \to \infty} \beta^t \lambda_t x_t = 0$, for $x_t \in \{K_{jt+1}, B_{jt}^H, B_{jt}^F\}$.

All the first order conditions are standard and can be easily recognised from the intertemporal consumption and investment theories. Equations (3.17)-(3.19) denote an expression for the marginal utility of consumption, λ_t, which is equal to the Lagrangian multiplier attached to the intertemporal budget constraint, an intertemporal Euler equation and a common risk-adjusted uncovered interest rate parity condition.

It is more convenient to express the remaining first order conditions relative to the marginal utility of consumption. By doing so, we obtain a Bellmann equation which derives the value of installed capital in terms of its replacement cost (e.g. the marginal Tobin's q).

$$q_t \varkappa_t \left[1 - \Upsilon\left(\frac{I_{jt}}{I_{jt-1}}\right) - \left(\frac{I_{jt}}{I_{jt-1}}\right)\Upsilon'\left(\frac{I_{jt}}{I_{jt-1}}\right)\right] + \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} q_{t+1} \varkappa_{t+1} \Upsilon'\left(\frac{I_{jt+1}}{I_{jt}}\right)\right]\left(\frac{I_{jt+1}}{I_{jt}}\right)^2 = 1 \tag{3.20}$$

$$q_t = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t}\left[(1-\delta) q_{t+1} + r^k_{t+1}\right]\right] \tag{3.21}$$

According to equation (3.21), the value of the current installed capital is derived from its expected future price, adjusted by the depreciation rate, and from the rental rate r^k_{t+1}. Both the period return and the expected future realisation of q are discounted using the pricing kernel $\beta \frac{\lambda_{t+1}}{\lambda_t}$.

3.1.2 Firms, Production and Price Setting

The economy comprises an intermediate goods sector that is populated by two continuums of domestic producers and importers. The former agents combine capital and labour to produce goods that are sold in the home market and exported, while the latter import a tradable good from the foreign country and resell it domestically.[7] Both producers act as price setters, being subject to Calvo-type nominal rigidities. As a result of staggered pricing in the import sector, there will be imperfect exchange rate pass-through at the consumer level.[8]

The individual outputs are combined in competitive markets by intermediate good retailers, who further sell their homogeneous product to a final competitive producer. An important observation concerns the nature of international trade in the model, which is carried out by intermediate firms only. By choosing such simplified trade linkages, our aim is to replicate the intensive use of imported intermediate inputs in production in the Czech Republic, previously documented by Ravenna and Natalucci (2008) and Laxton and Pesenti (2003). The setup we choose is also convenient because it creates a theoretical transmission mechanism through which nominal exchange rate depreciations, by increasing the domestic price of foreign inputs, result in adverse cost-push effects on domestic

[7]See the models developed by Bergin (2003) and Rabanal and Tuesta (2010) for similar production structures.

[8]Evidence of a low degree of exchange rate pass-through to consumer prices in the Czech Republic has been recently documented by Campa and Goldberg (2006).

output.[9] Accordingly, the design of our theoretical model accounts for the vulnerability of emerging economies to external shocks.[10]

Final Good Producer

As a result of the simplified trade linkages, the final good is nontraded, being used only for domestic consumption and investment purposes.[11] Aggregate output is obtained by combining domestic and foreign intermediate inputs, $Z_t^{h,d}$ and $Z_t^{f,d}$, using a CES technology:

$$Y_t = \left[\upsilon^{\frac{1}{\theta}} (Z_t^{h,d})^{\frac{\theta-1}{\theta}} + (1-\upsilon)^{\frac{1}{\theta}} (Z_t^{f,d})^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{3.22}$$

where $\theta > 0$ is the elasticity of substitution between domestic and foreign intermediate inputs, while υ represents the share of domestic added value in GDP.

To preserve the continuity of the presentation, it is useful to obtain the analytical form of a set of relative prices, expressed as a function of the effective terms of trade. The relative prices will be necessary for defining the decentralised allocation in a compact form that does not include nonstationary variables such as prices in levels.

Similarly to most of the literature, the terms of trade are defined as the domestic currency relative price of foreign goods:

$$T_t = \frac{P_t^f}{P_t^h} \tag{3.23}$$

By minimising the cost of supplying Y_t, the following relationship between the CPI and the sector specific price levels is obtained:

$$P_t = \left[\upsilon (P_t^h)^{1-\theta} + (1-\upsilon)(P_t^f)^{1-\theta} \right]^{\frac{1}{1-\theta}} = P_t^h J(T_t) \tag{3.24}$$

where the function $J(T_t)$ is related to the terms of trade by: $J(T_t) = \left[\upsilon + (1-\upsilon) T_t^{1-\theta} \right]^{\frac{1}{1-\theta}}$.

Taking first differences, the CPI inflation rate can be expressed as a function of π_t^h and changes in the terms of trade:

$$\pi_t = \frac{J(T_t)}{J(T_{t-1})} \pi_t^h \tag{3.25}$$

[9]See Svensson (2000, p.158) for a discussion of the additional transmission channels of monetary policy in an open-economy that are due to the nominal exchange rate.

[10]An additional channel through which nominal depreciations can have adverse effects in emerging economies is represented by the possibility of balance sheet deterioration. This research avenue has been introduced by Cespedes et al. (2004).

[11]See Kollmann (2001) and Laxton and Pesenti (2003) for similar assumptions.

The definition of the aggregate price level also enables us to obtain a set of identities regarding the relative prices in the economy:

$$\frac{P_t^h}{P_t} = \frac{1}{J(T_t)} \tag{3.26}$$

$$\frac{P_t^f}{P_t} = \frac{T_t}{J(T_t)} \tag{3.27}$$

As a result of staggered pricing in the import sector, the model rationalises a short-run gap between the price of the imported good in the foreign and domestic markets. Similarly to Monacelli (2006), we model these departures from the law of one price by:

$$\widetilde{MC}_t^f = \frac{S_t P_t^*}{P_t^f} \tag{3.28}$$

In our model, the "law of one price gap" is equal to the real marginal cost of the intermediate importers, a point that will be illustrated when characterising the relevant price setting problem. This explains why the above notation is used. Equations (3.27) and (3.28) enable us to obtain a model based definition of the real exchange rate:

$$RS_t = \frac{S_t P_t^*}{P_t} = \frac{S_t P_t^*}{P_t^f} \frac{P_t^f}{P_t} = \widetilde{MC}_t^f \frac{T_t}{J(T_t)} \tag{3.29}$$

It is also useful to express the one period variations in the nominal exchange rate in relation to the changes in RS_t and the difference between home and foreign CPI inflation rates.

$$\frac{S_t}{S_{t-1}} = \frac{RS_t}{RS_{t-1}} \frac{\pi_t}{\pi_t^*} \tag{3.30}$$

Taking into account the relative price expressions, the input demand functions associated with the cost minimisation problem of the final goods producer are given by:

$$Z_t^{h,d} = \left(\frac{P_t^h}{P_t}\right)^{-\theta} \upsilon Y_t = \left(\frac{1}{J(T_t)}\right)^{-\theta} \upsilon Y_t \tag{3.31}$$

$$Z_t^{f,d} = \left(\frac{P_t^f}{P_t}\right)^{-\theta} (1-\upsilon) Y_t = \left(\frac{T_t}{J(T_t)}\right)^{-\theta} (1-\upsilon) Y_t \tag{3.32}$$

Intermediate Good Producers

The intermediate goods sector is populated by two continuums of domestic producers and importers. In consideration of the different role played by these agents in international trade linkages, the individual production and price-setting decisions are analysed in separate sections. We begin by describing the choices made by domestic intermediate good firms.

Domestic Intermediate Good Producers

Since output produced by domestic agents is sold both at home and abroad, we need to introduce additional notation. To this end, let $Y_t^{h,d}$ define the aggregate demand for the domestically produced good and let the domestic and export components of $Y^{h,d}$ be defined by $Z_t^{h,d}$ and $Z_t^{x,d}$. An explicit relationship between the three variables cannot be specified unless we discuss how the price of the domestic intermediate good is set in each market. Here, we rule out the possibility of price discrimination across markets and impose the law of one price for domestic exports: $S_t P_t^x = P_t^h$.[12] Under producer currency pricing, the aggregate demand for the domestic good is defined as:

$$Y_t^{h,d} = Z_t^{h,d} + Z_t^{x,d} \tag{3.33}$$

We follow Justiniano and Preston (2010a) and assume a functional form for $Z_t^{x,d}$ that resembles equation (3.32):

$$Z_t^{x,d} = \chi_t \left(\frac{P_t^{h^*}}{P_t^*} \right)^{-\vartheta} Y_t^* = \chi_t \left(\frac{P_t^h}{S_t P_t^*} \right)^{-\vartheta} Y_t^* = \chi_t T_t^{\vartheta} \left(\widetilde{MC}_t^f \right)^{\vartheta} Y_t^* \tag{3.34}$$

where P_t^* and Y_t^* denote the price and output levels in the foreign economy, while $\vartheta > 0$ indicates the price elasticity of foreign demand. The quantity of the domestic good sold abroad also depends on a foreign demand shock χ_t, whose law of motion is given by:

$$\ln \chi_t = \rho_\chi \ln \chi_{t-1} + \sigma_\chi \varepsilon_{\chi,t} \ , \qquad \varepsilon_{\chi,t} \sim \mathbb{N}(0,1) \tag{3.35}$$

$Y_t^{h,d}$ is supplied as a bundle of differentiated varieties, indexed by $i \in [0,1]$ and produced by individual firms in a monopolistically competitive environment. The composite is obtained using a Dixit-Stiglitz aggregator:

$$Y_t^{h,d} = \left[\int_0^1 (Y_{it}^h)^{\frac{\rho-1}{\rho}} di \right]^{\frac{\rho}{\rho-1}} \tag{3.36}$$

where the elasticity of substitution across different varieties satisfies $\rho > 1$.

[12] As in Lubik and Schorfheide (2005); Monacelli (2006). Even though both Kollmann (2001) and Bergin (2003) use a pricing-to-market setup, their assumption is hard to be reconciled with the small open economy paradigm.

Due to the output loss caused by relative price dispersion under Calvo contracts, we distinguish between the definition of the CES composite, which stands for the total demand for the h good, and the aggregate supply, obtained by integrating over the continuum of producers : $Y_t^h = \int_0^1 Y_{it}^h di$. In general, $Y_t^h \neq Y_t^h$.

By minimising the total cost of supplying the composite good, subject to the aggregation constraint in (3.36), one can obtain the following demand function for each variety:

$$Y_{it}^h = \left(\frac{P_{it}^h}{P_t^h}\right)^{-\rho} Y_t^{h,d}, \qquad P_t^h = \left[\int_0^1 (P_{it}^h)^{1-\rho} di\right]^{\frac{1}{1-\rho}} \tag{3.37}$$

Capital and labour services are hired in economy-wide markets by domestic individual firms, who combine the two inputs to produce goods using a Cobb-Douglas technology:[13]

$$Y_{it}^h = \zeta_t K_{it}^{\alpha} (L_{it}^d)^{1-\alpha} - \phi \tag{3.38}$$

where the parameter $\phi > 0$ represents a fixed cost, while ζ_t denotes a neutral technology shock. Its exogenous law of motion is given by:

$$\ln \zeta_t = \rho_\zeta \ln \zeta_{t-1} + \sigma_\zeta \varepsilon_{\zeta,t} \ , \qquad \varepsilon_{\zeta,t} \sim \mathbb{N}(0,1) \tag{3.39}$$

Similarly to other studies, the calibration of ϕ ensures that firms do not obtain pure economic profits in steady state. Ruling out the theoretical possibility of firm entry/exit from the market is less problematic if such an assumption is made. Since no information on average profits could be found for the countries we examine, we cannot say if such a restriction is also empirically relevant.

Taking as given the nominal input prices W_t and R_t^k, intermediate firms optimally choose L_{it}^d and K_{it} to minimise the total cost of production, subject to the production function in (3.38). The problem can be stated in terms of the Lagrangian:

$$\mathfrak{L}(L_{it}^d, K_{it}, \psi) = W_t L_{it}^d + R_t^k K_{it} + \psi\Big(Y_{it}^h - \zeta_t K_{it}^{\alpha}(L_{it}^d)^{1-\alpha} + \phi\Big)$$

The first order conditions of this static optimisation problem are given by:

$$W_t = \psi(1-\alpha)\zeta_t\left(\frac{K_{it}}{L_{it}^d}\right)^{\alpha}, \qquad R_t^k = \psi\alpha\zeta_t\left(\frac{K_{it}}{L_{it}^d}\right)^{-(1-\alpha)}, \qquad Y_{it}^h = \zeta_t K_{it}^{\alpha}(L_{it}^d)^{1-\alpha} - \phi$$

Notice that the value of the Lagrange multiplier ψ corresponds to the nominal marginal cost, a result that is easily obtained by differentiating the functional $\mathfrak{L}$ with respect to

[13] Capital services are rented directly from households, whereas the labour input is made available via the homogenous bundle supplied by the labour market union.

output. Another important aspect of this economy is the constant return to scale property of technology which implies that all firms have the same capital-labour ratios. The result is a consequence of the assumption of economy-wide rental markets, which means that factor prices are the same to all producers.

$$\frac{K_{it}}{L^d_{it}} = \frac{\alpha}{1-\alpha}\frac{W_t}{R^k_t} \tag{3.40}$$

It is straightforward to show that the nominal marginal cost, also common across firms, is given by:

$$MC^h_t = \frac{1}{\zeta_t}\frac{1}{(1-\alpha)^{1-\alpha}}\frac{1}{\alpha^\alpha}W_t^{1-\alpha}(R^k_t)^\alpha \tag{3.41}$$

In setting the price for their products, firms face a Calvo-type inertial rule. Specifically, a fraction $1-\psi_p$ of the total number of firms is allowed to adjust prices. The pricing rule of these agents is implemented optimally as a function of future expected demand and cost conditions. On the other hand, the non-optimisers are assumed to index prices to past inflation in their sector. Their rule of adjustment is governed by the indexation parameter $\chi_p \in [0,1]$.

$$P^h_{it} = P^h_{it-1}(\pi^h_{t-1})^{\chi_p} \tag{3.42}$$

Firms maximise discounted lifetime profits, subject to the demand curve in (3.37), taking into account that they will not be able to adjust in future periods. The problem can be stated as:

$$\max_{P^h_{it}} E_t \sum_{s=0}^{\infty} (\beta\psi_p)^s \frac{\lambda_{t+s}}{\lambda_t}\frac{1}{\prod_{k=1}^s \pi_{t+k}}\left[\left(\prod_{k=1}^{s}(\pi^h_{t+k-1})^{\chi_p}P^h_{it} - MC^h_{t+s}\right)\left(\prod_{k=1}^{s}(\pi^h_{t+k-1})^{\chi_p}\frac{P^h_{it}}{P^h_{t+s}}\right)^{-\rho}Y^{h,d}_{t+s}\right] \tag{3.43}$$

The optimal solution $\tilde{P}^h_t$ must satisfy the following first order condition:

$$E_t\sum_{s=0}^{\infty}(\beta\psi_p)^s\lambda_{t+s}\prod_{k=1}^{s}\left(\frac{\pi^h_{t+k}}{\pi_{t+k}}\right)\left[\prod_{k=1}^{s}\left(\frac{(\pi^h_{t+k-1})^{\chi_p}}{\pi^h_{t+k}}\right)^{-\rho}\left[\prod_{k=1}^{s}\frac{(\pi^h_{t+k-1})^{\chi_p}}{\pi^h_{t+k}}(1-\rho)\left(\frac{\tilde{P}^h_t}{P^h_t}\right)+\rho\widetilde{MC}^h_{t+s}\right]Y^{h,d}_{t+s}\right]=0 \tag{3.44}$$

where the real marginal cost $\widetilde{MC}^h_t$ is defined as:

$$\widetilde{MC}^h_t = \frac{MC^h_t}{P^h_t} = \frac{1}{\zeta_t}\frac{1}{(1-\alpha)^{1-\alpha}}\frac{1}{\alpha^\alpha}w_t^{1-\alpha}(r^k_t)^\alpha\left(\frac{P_t}{P^h_t}\right) = \frac{1}{\zeta_t}\frac{1}{(1-\alpha)^{1-\alpha}}\frac{1}{\alpha^\alpha}w_t^{1-\alpha}(r^k_t)^\alpha J(T_t) \tag{3.45}$$

Note that the definition includes an open-economy specific wedge $\left(\frac{P_t}{P^h_t}\right)$, which arises as a result of the different price of intermediate and final goods. Hence, shocks that affect the terms of trade induce via their expenditure switching effects changes in the production costs of domestic firms.

The optimality condition (3.44) suggests that firms set prices in order to minimise a weighted average of deviations of future marginal revenues from future marginal costs. Higher weight is attached in the pricing scheme to periods where the agent expects a significant demand for her products. In the absence of nominal rigidities, equation (3.44) collapses to a standard flex price equilibrium condition, which states that the price level is equal to a markup over the nominal marginal cost in each period $\left(\tilde{P}_t^h = \frac{\rho}{\rho-1}\widetilde{MC}_{t+s}^h\right)$.

It is useful to express the price dynamics recursively, by rewriting the first order condition as:

$$\frac{\rho-1}{\rho}v_t^1 = v_t^2 \tag{3.46}$$

where the newly introduced variables are defined by:

$$v_t^1 = E_t\sum_{s=0}^{\infty}(\beta\psi_p)^s\lambda_{t+s}\prod_{k=1}^{s}\Big(\frac{\pi_{t+k}^h}{\pi_{t+k}}\Big)\prod_{k=1}^{s}\Big(\frac{(\pi_{t+k-1}^h)^{\chi_p}}{\pi_{t+k}^h}\Big)^{1-\rho}\Big(\frac{\tilde{P}_t^h}{P_t^h}\Big)Y_{t+s}^{h,d}$$

$$v_t^2 = E_t\sum_{s=0}^{\infty}(\beta\psi_p)^s\lambda_{t+s}\prod_{k=1}^{s}\Big(\frac{\pi_{t+k}^h}{\pi_{t+k}}\Big)\prod_{k=1}^{s}\Big(\frac{(\pi_{t+k-1}^h)^{\chi_p}}{\pi_{t+k}^h}\Big)^{-\rho}\widetilde{MC}_{t+s}^h Y_{t+s}^{h,d}$$

Letting $\tilde{p}_t^h = \frac{\tilde{P}_t^h}{P_t^h}$, the recursive form of v_t^1 and v_t^2 will satisfy:

$$v_t^1 = \lambda_t\tilde{p}_t^h Y_t^{h,d} + \beta\psi_p E_t\Big[\Big(\frac{\pi_{t+1}^h}{\pi_{t+1}}\Big)\Big(\frac{(\pi_t^h)^{\chi_p}}{\pi_{t+1}^h}\Big)^{1-\rho}\frac{\tilde{p}_t^h}{\tilde{p}_{t+1}^h}v_{t+1}^1\Big] \tag{3.47}$$

$$v_t^2 = \lambda_t\widetilde{MC}_t^h Y_t^{h,d} + \beta\psi_p E_t\Big[\Big(\frac{\pi_{t+1}^h}{\pi_{t+1}}\Big)\Big(\frac{(\pi_t^h)^{\chi_p}}{\pi_{t+1}^h}\Big)^{-\rho}v_{t+1}^2\Big] \tag{3.48}$$

In a symmetric equilibrium where all randomly selected firms choose the same price, the domestic intermediate goods price index will be equal to a probability weighted average of the price levels chosen by the optimising and non-optimising agents:[14]

$$(P_t^h)^{1-\rho} = \psi_p\Big(P_{t-1}^h(\pi_{t-1}^h)^{\chi_p}\Big)^{1-\rho} + (1-\psi_p)(\tilde{P}_t^h)^{1-\rho}$$

If the above law of motion is divided by $(P_t^h)^{1-\rho}$, one obtains:

$$1 = \psi_p\Big(\frac{(\pi_{t-1}^h)^{\chi_p}}{\pi_t^h}\Big)^{1-\rho} + (1-\psi_p)(\tilde{p}_t^h)^{1-\rho} \tag{3.49}$$

[14] See equation (3.37).

Intermediate Goods Importer

In order to make the model compatible with the international evidence on imperfect exchange rate pass-through (Engel, 1999) and, in particular, the evidence of low exchange rate pass-through into consumer prices in Central Europe (see Campa and Goldberg, 2006; Coricelli et al., 2006; Darvas, 2001), our model introduces nominal inertia in the short-run transmission of nominal exchange rate movements. The import price stickiness considered can be interpreted as an endogenous mechanism for generating deviations from the law of one price.[15]

The import sector is also populated by a continuum of firms, indexed on the unit interval by i. These agents buy goods in the foreign market at a marginal cost generically denoted by:

$$MC_t^f = S_t P_t^* \tag{3.50}$$

An immediate consequence of this assumption is that the law of one price holds at the border, but not at the producer level.[16] The individual outputs are packed by an import retailer who further sells the homogeneous bundle to final producers. His aggregation technology is given by:

$$Z_t^{f,d} = \left[\int_0^1 (Z_{it}^f)^{\frac{\rho-1}{\rho}} di \right]^{\frac{\rho}{\rho-1}} \tag{3.51}$$

Proceeding along the same lines as in the domestic intermediate sector, one can derive the individual demand functions:

$$Z_{it}^f = \left(\frac{P_{it}^f}{P_t^f} \right)^{-\rho} Z_t^{f,d}, \qquad P_t^f = \left[\int_0^1 (P_{it}^f)^{1-\rho} di \right]^{\frac{1}{1-\rho}} \tag{3.52}$$

The optimal price setting decision is analogous to equations (3.46)-(3.48). For analytical simplicity, however, we assume that no indexation takes place ($\chi_p^f = 0$).

$$\frac{\rho - 1}{\rho} f_t^1 = f_t^2 \tag{3.53}$$

$$f_t^1 = \lambda_t \tilde{p}_t^f Z_t^{f,d} + \beta \psi_p E_t \left[\frac{(\pi_{t+1}^f)^{\rho}}{\pi_{t+1}} \frac{\tilde{p}_t^f}{\tilde{p}_{t+1}^f} f_{t+1}^1 \right] \tag{3.54}$$

$$f_t^2 = \lambda_t \widetilde{MC}_t^f Z_t^{f,d} + \beta \psi_p E_t \left[\frac{(\pi_{t+1}^f)^{1+\rho}}{\pi_{t+1}} f_{t+1}^2 \right] \tag{3.55}$$

where the definition of the real marginal cost $\widetilde{MC}_t^f$ was already introduced in equation

[15] This is not entirely accurate, as the model implies deviations from the law of one price even in steady state. In the absence of a production subsidy, importers set their prices as a markup over marginal costs.
[16] See Kollmann (2001); Lubik and Schorfheide (2005); Monacelli (2006) for similar setups.

(3.28) as a measure of the law of one price gap.

$$\widetilde{MC}_t^f = \frac{S_t P_t^*}{P_t^f}$$

The import price index has the following law of motion:

$$1 = \psi_p (\pi_t^f)^{\rho-1} + (1-\psi_p)(\tilde{p}_t^f)^{1-\rho} \tag{3.56}$$

3.1.3 Monetary Policy

Monetary policy is delegated to an independent central bank, which sets nominal interest rates in response to deviations of inflation and output from steady state. Following the open economy feedback rules used in Justiniano and Preston (2010a) and Lubik and Schorfheide (2005), we allow for policy responses to changes in the real exchange rate and for inertial behaviour:[17]

$$\ln\Big(\frac{R_t}{R}\Big) = \chi_R \ln\Big(\frac{R_{t-1}}{R}\Big) + (1-\chi_R)\Big(\alpha_\pi \ln\Big(\frac{\pi_t}{\pi}\Big) + \alpha_y \ln\Big(\frac{Y_t}{Y}\Big) + \alpha_s \ln\Big(\frac{RS_t}{RS_{t-1}}\Big)\Big) + \nu_t \tag{3.57}$$

where the contemporaneous monetary policy shock follows a Gaussian white noise process:

$$\nu_t = \sigma_\nu \varepsilon_{\nu,t} \ , \qquad \varepsilon_{\nu,t} \sim \mathbb{N}(0,1) \tag{3.58}$$

When the model is estimated using Austrian data, we account for the different monetary policy regimes across the two countries by equating the domestic and foreign interest rates in all the structural equations. Darvas and Szapáry (2008) and Giannone et al. (2010) show that there has been a close historical alignment between the Austrian and the core European business cycles, in terms of their correlation and shock incidence. Based on this evidence, we assume throughout our work that the implementation of the area wide monetary policy by the ECB corresponds to the monetary stabilisation objectives in Austria. Consequently, the Taylor rule in equation (3.57) also designates the implementation of exogenous the monetary policy rule in the Austrian economy, which coincides by assumption to the common monetary policy stance of the ECB.

[17] A policy rule that responds to the nominal exchange rate would have a similar form to (3.57). The real exchange rate is chosen as a feedback variable because S_t will not appear in the loglinear model.

3.1.4 Aggregation and Market Clearing Conditions

A set of market clearing conditions must hold in the input, product and bond markets. Due to the competitive rental market for capital, the economy wide capital stock is obtained by aggregating across households, indexed by j:

$$K_t = \int_0^1 K_{jt} dj \tag{3.59}$$

The presence of relative wage dispersion under Calvo contracts creates an inefficiency factor that results in a wedge between the total number of hours supplied to the market (L_t) and the effective number of hours engaged by the union for producing the aggregate bundle L_t^d:[18]

$$L_t^d = \frac{L_t}{s_t^w}, \qquad \text{with} \quad s_t^w = \int_0^1 \left(\frac{w_{jt}}{w_t}\right)^{-\varphi} dj \quad \text{and } L_t \geq L_t^d \tag{3.60}$$

As Schmitt-Grohé and Uribe (2004) show, the law of motion of the state variable capturing the cost of relative wage dispersion is given by:

$$s_t^w = (1-\psi_w)\Big(\frac{\tilde{w}_t}{w_t}\Big)^{-\varphi} + (1-\psi_w)\psi_w\left(\frac{\pi_{t-1}^{\chi_w}}{\pi_t}\right)^{-\varphi}\left(\frac{\tilde{w}_{t-1}}{w_t}\right)^{-\varphi} + (1-\psi_w)\psi_w^2 \prod_{k=1}^{s}\left(\frac{\pi_{t+k-s-1}^{\chi_w}}{\pi_{t+k-s}}\right)^{-\varphi}\left(\frac{\tilde{w}_{t-2}}{w_t}\right)^{-\varphi} + \dots$$

$$s_t^w = (1-\psi_w)\sum_{s=0}^{\infty}\psi_w^s \prod_{k=1}^{s}\left(\frac{\pi_{t+k-s-1}^{\chi_w}}{\pi_{t+k-s}}\right)^{-\varphi}\left(\frac{\tilde{w}_{t-s}}{w_t}\right)^{-\varphi}$$

In recursive form, the law of motion of s_t^w becomes:

$$s_t^w = (1-\psi_w)\left(\frac{\tilde{w}_t}{w_t}\right)^{-\varphi} + \psi_w\left(\frac{w_{t-1}}{w_t}\frac{\pi_{t-1}^{\chi_w}}{\pi_t}\right)^{-\varphi} s_{t-1}^w \tag{3.61}$$

Since domestic intermediate firms have the same capital-labour ratio, the total output supplied to the market can be easily obtained by aggregating (3.38) :

$$Y_t^h = \int_0^1 \left[\zeta_t K_{it}^{\alpha}(L_{it}^d)^{1-\alpha} - \phi\right] di = \int_0^1 \left[\zeta_t\left(\frac{K_t}{L_t^d}\right)^{\alpha} L_{it}^d - \phi\right] di = \zeta_t K_t^{\alpha}(L_t^d)^{1-\alpha} - \phi$$

If a similar integration procedure is applied to equation (3.37), one obtains:

$$Y_t^h = s_t^p Y_t^{h,d}$$

[18] Schmitt-Grohé and Uribe (2004) show that $s_t^w \geq 1$.

where the relative price dispersion term s_t^p can be expressed as:[19]

$$s_t^p = \int_0^1 \left(\frac{P_{it}^h}{P_t^h}\right)^{-\rho} = (1-\psi_p)\sum_{s=0}^{\infty}\psi_p^s \prod_{k=1}^{s}(\pi_{t+k-s-1}^h{}^{\chi_p})^{-\rho}\left(\frac{\tilde{P}_{t-s}^h}{P_t^h}\right)^{-\rho}$$
$$= (1-\psi_p)(\tilde{p}_t^h)^{-\rho} + \psi_p\left(\frac{(\pi_{t-1}^h)^{\chi_p}}{\pi_t^h}\right)^{-\rho} s_{t-1}^p \qquad (3.62)$$

Equating the two expressions for Y_t^h, the following market clearing condition results:

$$\frac{\zeta_t K_t^{\alpha}(L_t^d)^{1-\alpha} - \phi}{s_t^p} = Y_t^{h,d} \qquad (3.63)$$

In the final product market, output must be equal to the sum of consumption and investment expenditures:

$$Y_t = C_t + I_t \qquad (3.64)$$

We assume that home debt is hold by residents only. As a result, the market clearing condition in the asset markets simply states that the domestic bond is in zero net supply:

$$B_t^H = 0\ , \quad \text{for all } t \qquad (3.65)$$

The remaining step in closing the model is to rearrange the intertemporal budget constraint of the economy. Making use of the market clearing conditions in (3.64)-(3.65) and the income definition of output, the resource constraint can be written as a law of motion of the net foreign assets position ($b_t^F = \frac{S_t B_t^F}{P_t}$):

$$\frac{b_t^F}{R_t^*\Omega(b_t^F)} = \frac{RS_t}{RS_{t-1}}\frac{b_{t-1}^F}{\pi_t^*} + \frac{P_t^h Z_t^{x,d}}{P_t} - \frac{P_t^f}{P_t}Z_t^{f,d}$$
$$= \frac{RS_t}{RS_{t-1}}\frac{b_{t-1}^F}{\pi_t^*} + \frac{1}{J(T_t)}Z_t^{x,d} - \frac{T_t}{J(T_t)}Z_t^{f,d} \qquad (3.66)$$

The last two terms denote the model based definition of the trade balance, which is equal to the difference between home exports ($Z_t^{x,d}$) and imports ($Z_t^{f,d}$) when evaluated in terms of the same numeraire.

Competitive Equilibrium

A stationary competitive equilibrium is a set of prices $\{\pi_t, \pi_t^h, \pi_t^f, q_t, r_t^k, w_t, \tilde{w}_t, \tilde{p}_t^h, \tilde{p}_t^f, T_t, S_t, RS_t, \widetilde{MC}_t^h, \widetilde{MC}_t^f\}$, allocations $\{C_t, I_t, Y_t, Y_t^{h,d}, Z_t^{h,d}, Z_t^{x,d}, Z_t^{f,d}, \lambda_t, L_t, L_t^d, K_{t+1}, b_t^F, x_t^1, x_t^2, v_t^1, v_t^2, f_t^1, f_t^2, s_t^w, s_t^p\}$ and policy rules $\{R_t\}$ satisfying (3.6), (3.13)-(3.21), (3.23), (3.25), (3.29)-(3.34),

[19] See (Schmitt-Grohé and Uribe, 2004, p.16-17) for a discussion of the properties of s_t.

(3.40), (3.45)-(3.49), (3.53)-(3.57), (3.60)-(3.64) and (3.66), given the shock processes $\{\varpi_t, \varsigma_t, \omega_t, \chi_t, \varkappa_t, \nu_t, \zeta_t\}_{t=0}^{\infty}$ and the exogenous stochastic paths followed by foreign variables $\{\pi_t^*, y_t^*, R_t^*\}_{t=0}^{\infty}$.[20]

3.2 Dynamics

Since the model does not admit a closed-form solution, the equilibrium dynamics are approximated by taking a log-linear approximation of the structural equations around the nonstochastic steady state.[21] As it is well known, a first-order solution method enables the researcher to express the dynamic system in a linear state-space form. When this is possible, the problem of evaluating the likelihood function is less challenging and can be easily tackled with the Kalman filter algorithm. In light of their computational tractability, first-order accurate solutions to DSGE models have become the norm in the macroeconometric literature. Accordingly, the empirical approach adopted by the present study follows the same tradition.

This section summarises the linearised rational expectations model and shows how the resulting structural equations can be mapped into a standard state-space representation. The mathematically oriented reader is invited to Appendix I, where the technical details of the derivations have been relegated.

The notation used follows standard conventions. Specifically, the realisation of an endogenous variable at the stationary state is defined by removing time subscripts, whereas a variable's log deviation with respect to the steady state is indicated by: $\hat{x}_t = \log(x_t) - \log(x)$.

Equations (3.67)-(3.68) illustrate the dynamic evolution of period t consumption, together with its marginal utility. Compared to the conventional Euler equation, the dynamics are enriched by the external habit persistence parameter γ and the preference shock $\hat{\varpi}_t$. As a result, current consumption is determined by a weighted average of its future and past realisations, by the evolution of *ex-ante* real interest rates and by unexpected temporary shifts in the discount factor. Observe that the weighting scheme depends on γ, which can influence the monetary policy's ability to induce changes in the consumption streams.

$$\hat{\lambda}_t = \hat{\varpi}_t - \frac{\sigma}{1-\gamma}\hat{C}_t + \frac{\sigma\gamma}{1-\gamma}\hat{C}_{t-1} \tag{3.67}$$

$$\hat{C}_t = \frac{\gamma}{1+\gamma}\hat{C}_{t-1} + \frac{1}{1+\gamma}E_t\hat{C}_{t+1} - \frac{1-\gamma}{(1+\gamma)\sigma}(\hat{R}_t - E_t\hat{\pi}_{t+1}) + \frac{1-\gamma}{(1+\gamma)\sigma}(\hat{\varpi}_t - E_t\hat{\varpi}_{t+1}) \tag{3.68}$$

[20] Equations (3.6), (3.20) and (3.40) enter in aggregate form. (3.40) is specified in terms of real factor prices, by deflating the denominator and the numerator of the RHS with P_t.

[21] See Appendix H.

The next three structural equations specify the behaviour of real investment flows in our model. The law of motion of the capital stock is standard; the only distinct element being the presence of the investment specific technological shock $\hat{\varkappa}_t$. Due to opportunity cost considerations, the value of installed capital ($\hat{q}_t$) in equation (3.70) is negatively related to the real interest rate. Similarly to the behaviour of other asset prices, its value is determined by its expected future value and the expected rental rate of return. Lastly, equation (3.71) states that investment dynamics are inertial and depend on shocks to the adjustment cost technology and the value of current installed capital.

$$\hat{K}_{t+1} = (1-\delta)\hat{K}_t + \delta(\hat{\varkappa}_t + \hat{I}_t) \tag{3.69}$$

$$\hat{q}_t = -(\hat{R}_t - E_t\hat{\pi}_{t+1}) + \frac{1-\delta}{1-\delta+r^k}E_t\hat{q}_{t+1} + \frac{1}{1-\delta+r^k}E_t\hat{r}^k_{t+1} \tag{3.70}$$

$$\hat{I}_t = \frac{1}{1+\beta}\hat{I}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{I}_{t+1} + \frac{\hat{q}_t}{\kappa(1+\beta)} + \frac{\hat{\varkappa}_t}{\kappa(1+\beta)} \tag{3.71}$$

The wage adjustment process implies that $\hat{w}_t$ responds to a weighted average of expected and past developments in the labour and goods markets. The mixture of forward and backward looking components is due to the richer dynamics induced by the possibility to partially index the nonoptimising Calvo contracts to past inflation. Households set wages in order to stabilise steady state deviations of the real wage from the marginal rate of substitution between consumption and labour. This average markup term appears in the last component of (3.72), being equal to $\hat{w}_t - m\hat{r}s_t = \hat{w}_t - \eta\hat{L}_t - \hat{\varpi}_t - \hat{\varsigma}_t + \hat{\lambda}_t$. Intuitively, when the average wage in the economy is below the level consistent with maintaining the desired marginal rate of substitution between consumption and labour, $\hat{w}_t$ will increase by an amount that is directly proportional to the degree of labour market inertia ψ_w.

$$\begin{aligned}\hat{w}_t = \frac{\beta}{1+\beta}E_t\hat{w}_{t+1} + \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\chi_w}{1+\beta}\hat{\pi}_{t-1} - \frac{1+\beta\chi_w}{1+\beta}\hat{\pi}_t + \frac{\beta}{1+\beta}E_t\hat{\pi}_{t+1} \\ - \frac{(1-\psi_w)(1-\beta\psi_w)}{\psi_w(1+\varphi\eta)}(\hat{\lambda}_t - \eta\hat{L}_t - \hat{\varpi}_t - \hat{\varsigma}_t + \hat{w}_t)\end{aligned} \tag{3.72}$$

Equation (3.73) represents a hybrid formulation of the New-Keynesian Phillips curve. Notice that the presence of the indexation parameter (χ_p) introduces backward-looking inertia in the standard adjustment process. Moreover, it also decreases the slope of the NKPC, as the latter depends on $\frac{1}{1+\beta\chi_p}$. In the absence of indexation ($\chi_p = 0$), this equation would resemble the purely forward looking adjustment rule of $\hat{\pi}^f_t$.

$$\hat{\pi}^h_t = \frac{\beta}{1+\beta\chi_p}E_t\hat{\pi}^h_{t+1} + \frac{\chi_p}{1+\beta\chi_p}\hat{\pi}^h_{t-1} + \frac{1}{1+\beta\chi_p}\frac{(1-\beta\psi_p)(1-\psi_p)}{\psi_p}\widehat{MC}^h_t \tag{3.73}$$

$$\hat{\pi}_t^f = \beta E_t \hat{\pi}_{t+1}^f + \frac{(1-\beta\psi_p)(1-\psi_p)}{\psi_p} \widehat{\hat{MC}}_t^f \tag{3.74}$$

As all steady state relative prices have been restricted to one, CPI inflation is equal to a weighted average of $\hat{\pi}_t^h$ and $\hat{\pi}_t^f$, with the weights being determined by the final output shares of intermediate production.

$$\hat{\pi}_t = \upsilon \hat{\pi}_t^h + (1-\upsilon)\hat{\pi}_t^f \tag{3.75}$$

In line with Monacelli (2006), the model rationalises two sources of deviations from PPP. On the one hand, an asymmetric degree of home bias allows for a traditional positive relationship between the real exchange rate and the terms of trade.[22] On the other hand, the imperfect transmission of exchange rate changes to consumer prices leads to a so-called law of one-price gap ($\widehat{\hat{MC}}_t^f$), which provides an additional factor for explaining the observed real exchange rate volatility.

$$\hat{RS}_t = \widehat{\hat{MC}}_t^f + \upsilon \hat{T}_t \tag{3.76}$$

The building blocks in (3.77)-(3.79) portray the UIP condition, the law of motion of the terms of trade and the monetary policy rule. In a similar manner to the first chapter of thesis, relaxing the stringent assumption of complete markets provides a stylised mechanism for explaining the forward premium rate puzzle. This is because expected changes in the nominal exchange rate do not depend only on the interest rate differential, but also on risk factors related to the net foreign assets position.

$$\hat{R}_t^* - \xi \hat{b}_t^F + \hat{\omega}_t + E_t \hat{RS}_{t+1} - \hat{RS}_t + E_t \hat{\pi}_{t+1} - E_t \hat{\pi}_{t+1}^* = \hat{R}_t \tag{3.77}$$

$$\hat{T}_t = \hat{T}_{t-1} + \hat{\pi}_t^f - \hat{\pi}_t^h \tag{3.78}$$

$$\hat{R}_t = \chi_R \hat{R}_{t-1} + (1-\chi_R)\alpha_\pi \hat{\pi}_t + (1-\chi_R)\alpha_y \hat{Y}_t + (1-\chi_R)\alpha_s(\hat{RS}_t - \hat{RS}_{t-1}) + \hat{\nu}_t \tag{3.79}$$

We showed earlier that the assumption of economy-wide rental markets implied that the capital-labour ratios of all producers were fully determined by the relative factor prices. By expressing the dynamics in equation (3.40) up to a first order degree of accuracy, we obtain a negative relationship between the number of hours hired by firms and the real wage. Moreover, as in Smets and Wouters (2003), the labour demand function imposes a unitary elasticity of price substitution with respect to $\hat{w}_t$.

$$\hat{L}_t = \hat{K}_t + \hat{r}_t^k - \hat{w}_t \tag{3.80}$$

[22] As the home economy is small, real expenditures allocated for the purchases of domestic goods in the foreign country have a negligible share of that consumption basket.

Owing to the specific aggregation technology, the income based definition of output specifies a close relationship between the first order dynamics of the final and intermediate aggregates. The exact functional form under which changes in productivity, the capital stock or the terms of trade are transmitted to $\hat{Y}_t$ is derived in Appendix I, after imposing the common assumption of zero steady state profits.[23]

$$\hat{Y}_t = \frac{\rho}{(\rho-1)\upsilon}\Big[\hat{\zeta}_t+\alpha\hat{K}_t+(1-\alpha)\hat{L}_t\Big]-\Big[\frac{1-\upsilon}{\upsilon}\vartheta+\theta(1-\upsilon)\Big]\hat{T}_t-\frac{1-\upsilon}{\upsilon}(\hat{\chi}_t+\vartheta\widehat{MC}_t^f+\hat{Y}_t^*) \quad (3.81)$$

On the other hand, the expenditure based market clearing condition of Y_t follows a standard loglinear form:

$$\hat{Y}_t = \Big[1-\frac{\delta\alpha}{r^k}\Big]\hat{C}_t + \frac{\delta\alpha}{r^k}\hat{I}_t \quad (3.82)$$

The domestic-side of the model is closed with the open-economy dynamics of the real marginal cost and the law of motion of the net foreign assets position:

$$\widehat{MC}_t^h = (1-\alpha)\hat{w}_t + \alpha\hat{r}_t^k - \hat{\zeta}_t + (1-\upsilon)\hat{T}_t \quad (3.83)$$

$$\frac{\beta}{\pi^*}\hat{b}_t^F = \frac{1}{\pi^*}\hat{b}_{t-1}^F + (1-\upsilon)Y\Big(\hat{\chi}_t + (\vartheta-1+\theta\upsilon)\hat{T}_t + \vartheta\widehat{MC}_t^f + \hat{Y}_t^* - \hat{Y}_t\Big) \quad (3.84)$$

Not previously introduced, foreign variables are exogenously given and correspond to the demeaned euro area inflation and interest rates and the HP-filtered level of output per capita. This sector is intended, on the one hand, to reflect the effects of foreign business cycles on domestic variables in a basic way. On the other hand, the external block of the model is treated as a structural feature of the economic environment. Based on the above considerations, the law of motion of the foreign variables is given by univariate AR(1) processes, which are estimated by OLS. By fitting these processes to the data, our approach can be best understood as a calibration of the foreign parameters prior to the empirical exercise.[24] Accordingly, we set $\rho_{y^*} = 0.887$, $\rho_{\pi^*} = 0.83$, $\rho_{r^*} = 0.943$ and $\sigma_{y^*} = 0.009$, $\sigma_{\pi^*} = 0.0011$, $\sigma_{r^*} = 0.001$.

$$\hat{Y}_t^* = \rho_{y^*}\hat{Y}_{t-1}^* + \sigma_{y^*}\varepsilon_{y^*,t}\ , \qquad \varepsilon_{y^*,t} \sim \mathbb{N}(0,1) \quad (3.85)$$

$$\hat{\pi}_t^* = \rho_{\pi^*}\hat{\pi}_{t-1}^* + \sigma_{\pi^*}\varepsilon_{\pi^*,t}\ , \qquad \varepsilon_{\pi^*,t} \sim \mathbb{N}(0,1) \quad (3.86)$$

$$\hat{R}_t^* = \rho_{r^*}\hat{R}_{t-1}^* + \sigma_{r^*}\varepsilon_{r^*,t}\ , \qquad \varepsilon_{R^*,t} \sim \mathbb{N}(0,1) \quad (3.87)$$

The log-linear system sets up a probability model for 28 variables, which can be sum-

[23] See Christiano et al. (2005) and Schmitt-Grohé and Uribe (2006).

[24] If the foreign block would be included in the Bayesian estimation, we would also have to formulate and to justify reasonable prior distributions for the 6 parameters. This can prove a rather difficult task in view of the stylised autoregressive processes we assume.

marised by the vector of states:

$$s_t = \begin{pmatrix} \hat{Y}_t, \hat{C}_t, \hat{L}_t, \hat{I}_t, \hat{K}_t, \hat{w}_t, \hat{r}_t^k, \hat{\lambda}_t, \hat{\pi}_t, \hat{\pi}_t^h, \hat{\pi}_t^f, \hat{q}_t, \hat{b}_t^F, \hat{RS}_t, \hat{R}_t, \\ \hat{T}_t, \widehat{MC}_t^h, \widehat{MC}_t^f, \hat{Y}_t^*, \hat{\pi}_t^*, \hat{R}_t^*, \hat{\zeta}_t, \hat{\varsigma}_t, \hat{\varpi}_t, \hat{\omega}_t, \hat{\chi}_t, \hat{\varkappa}_t, \hat{\nu}_t \end{pmatrix}'$$

For a given set of structural parameters, the solution of the linear rational expectations model is obtained with Dynare, a Matlab DSGE-solution toolbox developed by Michel Juillard and others.[25] Among the standard procedures that can be applied to compute the solution of linearised system, the implementation in Dynare is based on the generalised Schur decomposition approach of Sims (2002). Once this algorithm is applied, the output of the perturbation results in the state equation given below:

$$s_t = A(\Theta)s_{t-1} + B(\Theta)\epsilon_t \ , \qquad \epsilon_t \sim \mathbb{N}(0, \mathrm{I}) \tag{3.88}$$

In the restricted VAR(1) representation, the vector of state variables s_t evolves as a function of its past realisations and conditionally on the paths followed by the exogenous shocks $\epsilon_t = (\varepsilon_{\zeta,t}, \varepsilon_{\varpi,t}, \varepsilon_{\varsigma,t}, \varepsilon_{\omega,t}, \varepsilon_{\chi,t}, \varepsilon_{\varkappa,t}, \varepsilon_{\nu,t}, \varepsilon_{y^*,t}, \varepsilon_{\pi^*,t}, \varepsilon_{r^*,t})'$. The mapping depends on the matrices $A(\Theta)$ and $B(\Theta)$, which determine the nonlinear influence of the structural parameters on the dynamics.

The state-space representation is complemented with a measurement equation whose role is to relate the model's variables to the observables:

$$\mathbb{Y}_t = \begin{pmatrix} \Delta\ln(Y_t^{obs}) - \gamma_Y \\ \Delta\ln(C_t^{obs}) - \gamma_C \\ \Delta\ln(w_t^{obs}) - \gamma_w \\ \pi_t^{obs} - \pi \\ R_t^{obs} - R \\ \ln(L_t^{obs}) - \mu_L \\ \ln(RS_t^{obs}) - \gamma_{RS} \cdot t \\ \ln(Y_t^*) - \ln(Y_{HP,t}^*) \\ \pi_t^* - \pi^* \\ R_t^* - R^* \end{pmatrix} = \begin{pmatrix} \hat{Y}_t - \hat{Y}_{t-1} \\ \hat{C}_t - \hat{C}_{t-1} \\ \hat{W}_t - \hat{W}_{t-1} \\ \hat{\pi}_t \\ \hat{R}_t \\ \hat{L}_t \\ \hat{RS}_t \\ \hat{Y}_t^* \\ \hat{\pi}_t^* \\ \hat{R}_t^* \end{pmatrix} \tag{3.89}$$

Our empirical study is carried out based on ten macroeconomic series: real output, real consumption (all expressed in per capita terms), real wages, CPI inflation, total hours,

[25]see http://www.cpremap.cnrs.fr/dynare. Dynare is also used to estimate the structural model.

the real exchange rate, the short-term interest rate and the foreign levels of output, inflation and nominal interest rate. In reading the observables equation, it becomes apparent that an exact mapping between the theoretical and the empirical series requires that the latter be transformed. This is because our model is only intended at comparing the cyclical characteristics of the Austrian and Czech data, whereas the unaltered macroeconomic time-series typically display unit roots. The transformation process we choose to induce stationarity in the data is guided by the results obtained from ADF unit root tests. Specifically, the output, consumption and real wage series are rendered stationary by expressing them in terms of detrended growth rates.[26] On account of the different time-series properties of international relative prices, the Czech real exchange rate is expressed in terms of deviations from a linear trend, whereas the Austrian counterpart was found stationary and therefore demeaned. Another asymmetry between the two countries involves the inflation and interest rate series. As a result of the persistent disinflation process in the Czech Republic, these variables are detrended by a time-varying inflation target. On the other hand, π is constant in the case of the Austrian economy and reflects the conventional modelling of the inflation objective. Further details are given in the Data section.

An important issue that needs to be properly addressed when estimating DSGE models concerns the problem of stochastic singularity (see An and Schorfheide, 2007, p.124). Unless the shock structure appearing in the state-space representation is sufficiently rich, with the number of disturbances being at least equal to the number of observables, the model will be confronted with a serious form of model misspecification. The methodological flaw entails a rank deficient covariance matrix of $\mathbb{Y}_t$, which appears due to the possibility of expressing a subset of observable variables as a linear combination of other observables. Moreover, if the forecast error covariance matrix is singular, any inference exercise would be simply impossible: e.g. the likelihood function would be equal to $-\infty$. Following Christiano et al. (2008); Lubik and Schorfheide (2005) and Rabanal and Tuesta (2010), our empirical strategy is to select a number of observable variables that is equal to the number of structural shocks. To this end, this paper adopts the strong form interpretation of DSGE models and refrains from imposing any measurement errors that would account for potential model misspecification.[27]

[26]In (3.89), the sample means of the growth rates are represented by γ_Y,γ_C and γ_w.
[27]See Smets and Wouters (2003) for a discussion.

3.3 Estimation Methodology

In this section, the remaining steps of the estimation procedure are presented. To keep the discussion self-contained, we first review the main differences between classical and Bayesian approaches to statistical inference. The interested reader can find a more extensive coverage of the topic in standard textbooks covering Bayesian analysis, such as Berger (1985) and Robert (2007). We then introduce the Kalman Filter and the Metropolis-Hastings algorithms, which are the main tools needed to evaluate the likelihood function and to characterise the posterior distribution, respectively.

3.3.1 The Bayesian Approach to Statistical Inference

The essential difference between classical (frequentist) and Bayesian statistical methods concerns the treatment of the vector of structural parameters Θ.

By considering Θ an unknown but fixed quantity, the classical statistical analyst derives estimators which converge to the 'true' population value in repeated samples and have good asymptotic properties (i.e unbiasedness, efficiency). The performance evaluation of such procedures is based on the probability distribution of the data implied by the statistical model. Moreover, it involves statistical tests that are assessed according to various measures (i.e. confidence intervals, p-values), all of which are obtained by conditioning on Θ and by integrating over all the potential data. As a result of the last observation, classical procedures have desirable properties before knowing which sample of data has been observed. For the purpose of our discussion, the key attributes of frequentist methods are that: (i) the vector of parameters is an unknown but fixed quantity and ii) the estimation process involves conditioning on Θ and integrating over (potentially unobservable) data.

The validity of a classical statistical analysis critically depends on the degree upon which the model is an accurate description of reality and on the ability to replicate an experiment using different samples. Whereas the former requirement is essential to any statistical procedure, the latter can be very hard to meet in context of time-series applications involving empirical DSGE models. Specifically, a frequentist design of a statistical experiment can perform well if a coin is tossed n times. In this case, both assumptions mentioned above are met, as the true conditional likelihood function implied by the model is known in advance and the experiment can be easily replicated. In contrast, classical methods can be hardly reconciled with the non-repetitive nature of statistical phenomena. For instance, an empirical macroeconomist will typically have access to a single sample of observed series, being impossible to imagine even how his dataset can be replicated. The essential idea is that in most instances of applied work the frequency concept does not apply (see Berger, 1985). Several other criticisms can be put forward to the use of classical statistical methods in the context of our application. First, the inherent falseness of models questions the very existence of a true population parameter if the theoretical representation of the data generating process is wrong (see Robert, 2007, p.508-509). Such a possibility is always a potential concern in the macroeconomics literature. Second, the relatively low ratio between the number of observations and the number of estimated parameters, that typically occurs in empirical DSGE applications, makes the use of such methods less attractive in small samples.[28] As Scheines et al. (1999, p.39) discuss, relying on asymptotic results in these circumstances is neither reliable, nor robust if maximum likelihood procedures are applied. Finally, the existence of multiple optimum points and the presence of flat likelihood surfaces in certain dimensions of the parameter space increases both the complexity and the computational effort needed to maximise the DSGE likelihood function. More often than not, the classical maximum likelihood estimates are largely at odds with the evidence arising from VARs. As we shall see, if the likelihood function is reweighted with prior information, the increased curvature of the posterior kernel can help alleviate the problems associated with the optimisation routines. By doing so, the estimation will also be characterised by better identified parameters.

In contrast to the frequentist approach, the theoretical foundation for Bayesian statistical analysis is an inversion process which uses the effects of a random phenomenon, summarised by a set of observations, in order to make an inference about the set of parameters directing that phenomenon. Owing to a more general treatment of the notion of probability, which captures the beliefs a researcher has in an event, Θ is a vector of random variables under the Bayesian perspective. Rather than conditioning on the vector of parameters and integrating over potential data, the Bayesian perspective does exactly the opposite. It makes probability statements by integrating over the random Θ, while conditioning on the data. This "axiomatic reduction from the notion of unknown [parameter] to the notion of random [parameter]" (Robert, 2007) is justified as a result of a different scope of a probability model. In contrast to the frequentist approach, a probability model is considered a tool for understanding a real-world phenomenon, rather than for providing a full explanation of it.

The Bayesian inference process requires both a sampling model (as in the classical ap-

[28] We use observations for ten macroeconomic time-series spanning a sixty quarter period, whereas the number of estimated parameters is equal to twenty-eight. Hence, our study could be easily subject to such a critique if the classical approach were adopted. The modelling problems created by small samples of reliable data in transition economies are discussed in Amato and Gerlach (2001).

proach) and a prior distribution on all the components of Θ. These two inputs are sufficient for characterising the conditional distribution of the unknown parameters given the observed data, also known as the posterior distribution. In fact, the above sufficiency is an immediate consequence of the direct mapping that exists between the conditional distributions of the observations and parameters, known as Bayes' Theorem:

$$p(\Theta|\mathbb{Y}) = \frac{p(\mathbb{Y}|\Theta)p(\Theta)}{\int_{\Theta} p(\mathbb{Y}|\Theta)p(\Theta)d\Theta} \tag{3.90}$$

The formula simply states that the posterior density $p(\Theta|\mathbb{Y})$ represents a compromise between prior beliefs and the data. These two concepts are included through the prior distribution $p(\Theta)$ and the sample density $p(\mathbb{Y}|\Theta) \equiv \mathbb{L}(\Theta|\mathbb{Y})$, which is interpreted as the likelihood function once the data have been observed.[29] The weighting scheme used to update the posterior density also depends on the term appearing in the denominator, which defines the marginal distribution of $\mathbb{Y}$: $p(\mathbb{Y}) = \int_{\Theta} p(\mathbb{Y}|\Theta)p(\Theta)d\Theta$.

Intuitively, Bayes' Theorem shows how the information contained in the data can be extracted in order to produce a revised estimate of the conditional distribution of Θ. Notice that the updating process requires the specification of a prior distribution $p(\Theta)$, which is "the key to Bayesian inference and its determination is therefore the most important step in drawing this inference" (Robert, 2007). In many applications, including prior information in the estimation process is a meaningful advantage, which can make an effective use of past empirical evidence and the uncertainty surrounding the estimates of the structural parameters. For instance, if this information is inconclusive and sparse, it should be reflected in a more dispersed prior distribution. Likewise, strong evidence regarding particular values of parameters should be incorporated in the estimation process through a tight prior distribution. If the prior distribution can be formulated without too much uncertainty surrounding a particular choice, the Bayesian inference can be conducted mechanically, being the only internally consistent statistical paradigm (as discussed in Berger, 1985; Robert, 2007). Although including prior information is desirable and even necessary in many applications, the need to translate prior beliefs into appropriate distributions introduces a nontrivial technical element into the analysis. On the one hand, the (scarce) available information will typically result in more than one potential distribution being compatible with the prior knowledge. On the other hand, the subjective input that is typically associated with prior beliefs can give rise to a different scope for abuse in statistics. For instance, the element of uncertainty characterising the specification of prior beliefs gives a malevolent or not properly trained researcher the possibility to obtain

[29] Since $p(\mathbb{Y}|\Theta)$ is the only component through which the empirical information about Θ enters the posterior density, it becomes clear that Bayesian methods always conform to the Likelihood Principle.

the answer one wishes. In this study, we try get around such objections to our analysis by properly documenting the choice of our prior distributions in relation to other studies. Second, we employ a robust Bayesian approach by assessing how sensitive the posterior results are to different specifications of the prior distribution. To this end, our aim is to alleviate the potential concerns that might be raised with respect to the influence of subjective inputs on our final results.

Armed with the definition of the posterior density, the implementation of the Bayesian procedure we employ requires the following steps:

1. Set the priors of the parameters to be estimated.
2. Evaluate the likelihood function based on the linear state-space representation by applying the Kalman filter.
3. Sample 500,000 draws from the joint posterior kernel using the Random Walk Metropolis algorithm.
4. Compute the marginal likelihood of the model numerically. Draw inferences about posterior quantities of interest, which include variance decompositions, impulse response functions and other statistics that are a function of Θ.

While the prior selection is explored in section 3.4.1, here we briefly discuss the remaining steps of the estimation methodology.[30] The reader is referred to An and Schorfheide (2007); Canova (2007) and Fernández-Villaverde (2010) for a more detailed explanation of Bayesian inference in DSGE models.

3.3.2 The Kalman Filter

The Kalman filter is a convenient algorithm that allows one to construct the likelihood function associated with linear state-space representations. In the context of our application, the state and measurement equations have a structure which allows for cross-correlation between the state and measurement errors:

$$s_t = A(\Theta)s_{t-1} + B(\Theta)\epsilon_t, \qquad \epsilon_t \sim \mathbb{N}(0, \mathrm{I}) \tag{3.91}$$

$$\mathbb{Y}_t = C(\Theta)s_t + D(\Theta)\epsilon_t \tag{3.92}$$

[30] The posterior simulations are performed in Dynare.

Using the properties of joint densities, the log-likelihood function of observing the sample data can be expressed as:

$$\ln p(\mathbb{Y}_1, \mathbb{Y}_2, \ldots, \mathbb{Y}_T|\Theta) = \sum_{t=0}^{T-2} \ln p(\mathbb{Y}_{T-t}|\mathbb{Y}_{T-t-1}, \mathbb{Y}_{T-t-2}, \ldots, \mathbb{Y}_1, \Theta) + \ln p(\mathbb{Y}_1|\Theta) \quad (3.93)$$

Although computing so many quantities may appear to be very difficult, the assumption of normally distributed innovations in the state-space representation simplifies the likelihood evaluation in two important dimensions. First, it implies that the conditional densities in (3.93) are also Gaussian. In addition, the first and second moments of each conditional distribution are sufficient to fully characterise the likelihood objects. One advantage of the Kalman filter in this sense is that it provides a recursive procedure to compute the conditional means and variances of the data, using a prediction error decomposition approach.

The algorithm begins by setting a pre-observation distribution for the vector of states, which is typically initialised at the unconditional mean and covariance matrix. Once some data have been observed, the Kalman filter generates optimal linear predictors of next period observations, using the information set available until then ($\mathcal{I}_{t-1}$). Specifically, the conditioning on the $t-1$ period results in the following forecasts of the state mean and MSE covariance matrix:

$$s_{t|t-1} = E(s_t|\mathcal{I}_{t-1}) = As_{t-1|t-1} \quad (3.94)$$

$$P_{t|t-1} = E\Big[(s_t - s_{t|t-1})(s_t - s_{t|t-1})'|\mathcal{I}_{t-1}\Big] = AP_{t-1|t-1}A' + BB' \quad (3.95)$$

Let us define by η_t the one step ahead forecast error made in predicting $\mathbb{Y}_t$. From the measurement equation, one can easily derive that:

$$\eta_t = \mathbb{Y}_t - \mathbb{Y}_{t|t-1} = C(s_t - s_{t|t-1}) + D\epsilon_t \quad (3.96)$$

The mean squared error associated with this prediction is:

$$\begin{aligned}\Sigma_{t|t-1} = E(\eta_t\eta_t') &= E\Big[\Big(C(s_t - s_{t|t-1}) + D\epsilon_t\Big)\Big(C(s_t - s_{t|t-1}) + D\epsilon_t\Big)'\Big] \\ &= CP_{t|t-1}C' + DD' + CBD' + DB'C' \quad (3.97)\end{aligned}$$

The last two results are important, as they enable us to characterise the density of the forecast error using the first and second order moments: $\eta_t \sim \mathbb{N}(0, \Sigma_{t|t-1})$. It is not immediately obvious how the one step ahead forecast error and the likelihood function are related, as the latter depends on sum of the conditional densities of $\mathbb{Y}_{t|t-1}$. Still, the linear relationship between η_t and $\mathbb{Y}_{t|t-1}$ in (3.96) implies that the two variables are identically distributed. For this reason, the log-likelihood can be written in terms of the prediction error decomposition specified below:

$$\ln p(\mathbb{Y}|\Theta) = -\Big[\frac{Tm}{2}\ln(2\pi) + \frac{1}{2}\sum_{t=1}^{T}\ln\Big|\Sigma_{t|t-1}\Big|\Big] - \frac{1}{2}\sum_{t=1}^{T}\eta_t(\Sigma_{t|t-1})^{-1}\eta_t' \tag{3.98}$$

where m represents the number of series in the data.

The final step required for implementing the Kalman filter is to update the inferences about the state vector once a new realisation of $\mathbb{Y}_t$ is observed. Let $s_{t|t}$ be the updated estimate of the state vector. In order to obtain forecasts of s_t that are unbiased ex-ante, we must ensure that the errors made in estimating the observables are the best linear predictors of the state updating errors. If this is the case, then the following moment condition holds:

$$E\Big[[(s_t - s_{t|t-1}) - F'\eta_t]\eta_t'\Big] = 0 \tag{3.99}$$

The coefficient matrix F' is such that it generates the smallest mean squared error prediction of s_t among the class of linear forecasting rules. Using the last equation, one can obtain an estimate of s_t that corresponds to a standard formula of updating a linear projection:[31]

$$s_{t|t} = s_{t|t-1} + E\Big[(s_t - s_{t|t-1})\eta_t'\Big]\Big[E(\eta_t\eta_t')\Big]^{-1}\eta_t \tag{3.100}$$

The correction rule simply says that the revised estimate of the state variable, using an augmented information set, is a function of its past estimate and the current prediction error made in forecasting the observables. The correction factor is equal to $\mathbb{K}_t = E\Big[(s_t - s_{t|t-1})\eta_t'\Big]\Big[E(\eta_t\eta_t')\Big]^{-1}$, known as the Kalman gain.

We can substitute (3.96) and (3.97) into the last expression to obtain:

$$\begin{aligned} s_{t|t} &= s_{t|t-1} + (P_{t|t-1}C' + BD')\Big(CP_{t|t-1}C' + DD' + CBD' + DB'C'\Big)^{-1}(y_t - Cs_{t|t-1}) \\ &= s_{t|t-1} + \mathbb{K}_t(y_t - Cs_{t|t-1}) \end{aligned} \tag{3.101}$$

The updated prediction of the state variable has a covariance matrix given by:

$$\begin{aligned} P_{t|t} &= E\Big[(s_t - s_{t|t})(s_t - s_{t|t})'\Big] = E\Big[(s_t - s_{t|t-1} - \mathbb{K}_t\eta_t)(s_t - s_{t|t-1} - \mathbb{K}_t\eta_t)'\Big] \\ &= P_{t|t-1} + \mathbb{K}_t\Sigma_{t|t-1}\mathbb{K}_t' - \mathbb{K}_tE\Big[\eta_t s_t'\Big] - E\Big[s_t\eta_t'\Big]\mathbb{K}_t' \\ &= P_{t|t-1} + \mathbb{K}_t\Sigma_{t|t-1}\mathbb{K}_t' - \mathbb{K}_t(CP_{t|t-1} + DB') - (P_{t|t-1}C' + BD')\mathbb{K}_t' \end{aligned} \tag{3.102}$$

In summary, the evaluation of the likelihood function using the Kalman filter entails choosing appropriate initial conditions for the vector of state variables. Next, the one

[31] See Hamilton (1994, p. 74-75).

step-ahead forecasts of $s_{t|t-1}$ and $P_{t|t-1}$ are generated according to equations (3.94) and (3.95). Once the t period observations are gathered, the previous estimates are revised as implied by (3.101)-(3.102). The recursive estimate-update process is repeated until the number of periods reaches the sample size T. Finally, the log-likelihood function is evaluated using the prediction error decomposition in (3.98).

3.3.3 The Metropolis Algorithm

Since the posterior density is analytically intractable and does not belong to any family of standard distributions, random samples from $p(\Theta|\mathbb{Y})$ cannot be generated directly. Despite this inconvenience, the development of sophisticated simulation techniques over the past decades has permitted the stochastic exploration of the likelihood surface using iterative methods. Commonly known as Monte Carlo Markov Chain (MCMC), these procedures allow the researcher to generate random draws from the posterior distribution even if the latter does not have a known functional form and direct sampling is impossible. Nonetheless, the implementation of MCMC algorithms relies on the fact that the posterior density can still be evaluated up to a constant of proportionality by applying the Kalman filter. In what follows, we will refer to this target distribution as the posterior kernel: $\tilde{p}(\Theta|\mathbb{Y}) = p(\mathbb{Y}|\Theta)p(\Theta) \propto p(\Theta|\mathbb{Y})$.

MCMC methods involve the construction of a transition distribution whose draws form a Markov chain. Under certain regularity conditions, the sequence of iterations/random variables obtained from the transition kernel has the property of converging in distribution to the target density we need to sample from. Hence, as Gelman et al. (2003) observe, "the key to the method's success is not the Markov property, but rather that the approximate [transition] distributions are improved at each step in the simulation, in the sense of converging to the target".

The specific MCMC method we employ is the Random Walk Metropolis algorithm, whose implementation can be described as follows:[32]

(a) Use a numerical optimisation routine to determine the value of Θ that maximises the posterior kernel $\tilde{p}(\Theta|\mathbb{Y})$.[33] Let $\tilde{\Theta}$ and H denote the posterior mode and the Hessian

[32] Our exposition of the Metropolis algorithm reflects the presentations in An and Schorfheide (2007) and Gelman et al. (2003).

[33] The posterior mode was computed with the csminwel optimisation routine written by Christopher Sims. To ensure that the parameter space is properly spanned and that we do not end up computing a local optimum, we initialised the procedure with various combination of parameter values sampled from the prior distribution.

matrix, which corresponds to the second derivative matrix of the log posterior evaluated at the posterior mode. And let Σ_m be defined as $\Sigma_m = -H = -\frac{\partial^2 \ln\, \tilde{p}(\Theta|\mathbb{Y})}{\partial\Theta\partial\Theta'}\Big|_{\Theta=\tilde{\Theta}}$.

If the posterior kernel is unimodal, roughly symmetric and twice differentiable, then $\tilde{p}(\Theta|\mathbb{Y})$ can be locally approximated around $\tilde{\Theta}$ using a second order Taylor expansion:

$$\ln \tilde{p}(\Theta|\mathbb{Y}) \approx \ln \tilde{p}(\tilde{\Theta}|\mathbb{Y}) + \frac{\partial \ln\, \tilde{p}(\Theta|\mathbb{Y})}{\partial\Theta}\Big|_{\Theta=\tilde{\Theta}} (\Theta-\tilde{\Theta}) + \frac{1}{2}(\Theta-\tilde{\Theta})'\left[\frac{\partial^2 \ln\, \tilde{p}(\Theta|\mathbb{Y})}{\partial\Theta\partial\Theta'}\Big|_{\Theta=\tilde{\Theta}}\right](\Theta-\tilde{\Theta})$$

Since $\tilde{\Theta}$ maximises the posterior kernel, the second term in the expansion will be zero. It follows that:

$$\ln\, \tilde{p}(\Theta|\mathbb{Y}) \approx \ln\, \tilde{p}(\tilde{\Theta}|\mathbb{Y}) - \frac{1}{2}(\Theta-\tilde{\Theta})'\Sigma_m(\Theta-\tilde{\Theta})$$

Or equivalently:

$$\tilde{p}(\Theta|\mathbb{Y}) = \exp\Big[\ln\, \tilde{p}(\tilde{\Theta}|\mathbb{Y}) - \frac{1}{2}(\Theta-\tilde{\Theta})'\Sigma_m(\Theta-\tilde{\Theta})\Big] \propto \mathbb{N}(\tilde{\Theta}, \Sigma_m^{-1})$$

The purpose of the first step is to create an estimate of the location of the target density. In addition, it serves as a convenient choice of initialising the iterative simulation.

(b) Sample Θ^0 from $\mathbb{N}(\tilde{\Theta}, c\Sigma_m^{-1})$, where c is a scale parameter whose role is to tune the proportion of accepted draws.

Let the transition distribution be defined by a random walk process:

$$\mathbb{J}_t(\Theta^*|\Theta_{t-1}) = \Theta_{t-1} + \Psi_t, \quad \text{with} \quad \Psi_t \sim \mathbb{N}(0, c\Sigma_m^{-1})$$

(c) For t=1,2,...,n_{draws}

Draw a proposed realisation Θ^* from the transition distribution. Solve the linearised DSGE model and derive its state-space representation. Evaluate the posterior kernel $p(\Theta^*|\mathbb{Y}) = p(\Theta^*)p(\mathbb{Y}|\Theta^*)$ using the Kalman filter.

Compute the ratio of probabilities

$$r = \frac{p(\Theta^*|\mathbb{Y})}{p(\Theta_{t-1}|\mathbb{Y})}$$

(d) Update the value of Θ^* according to the following rule:

If $r \geq 1$, set $\Theta_t = \Theta^*$; If $0 \leq r < 1$, set $\Theta_t = \Theta^*$ with probability r, and $\Theta_t = \Theta_{t-1}$ with probability $1 - r$.

In essence, the Metropolis algorithm devises a rule of sampling from the posterior kernel in such a way that it always accepts the jumps that have a higher likelihood (e.g the probability ratio r is larger than one). From this point of view, the Metropolis can be regarded as "a stepwise mode finding algorithm" (Gelman et al., 2003). On the other hand, proposals that move Θ_{t-1} to regions of the posterior kernel that have a lower probability attached are only sometimes accepted. In this way, the random sampling procedure ensures that the whole posterior density is explored. An optimal crossing through all the relevant probability regions also depends on the acceptance rates, which should generally be somewhere between $20 - 30\%$ when the number of estimated parameters is large.

In our study, the posterior inferences are drawn by sequentially running three parallel Markov chain iterations, with initial values equally dispersed around the posterior mode. From each chain 500,000 draws are sampled, with the first 100,000 draws being discarded in order to diminish the influence of the initial values on inference. The scale parameter c that influences the variance of the transition kernel was set at 0.38 and 0.33 in the case of the Czech and Austrian simulations respectively. In both cases, we obtained acceptance rates of approximately 25%. Finally, the convergence of each Markov chain has been assessed (and confirmed) according to the qualitative diagnostics developed by Brooks and Gelman (1998).

3.3.4 Data Description

The empirical exercise is conducted based on National Accounts data available in the Eurostat New Cronos and OECD databases. We use the 1996Q1-2011Q4 sample period and treat seven macroeconomic series as directly observable: real per capita consumption, real per capita output, the real wage, total hours, CPI inflation, the short-term interest rate and the real exchange rate. A few comments are necessary to fully describe the data transformation process. Owing to the absence of fiscal policy considerations, a preliminary step is to recognise the real world analogues to the model's variables. Specifically, C_t is defined as real consumption expenditures by households, whereas investment flows are reflected in the data through the gross capital formation measure. Similarly to Smets and Wouters (2005) and Justiniano and Preston (2010a), nominal wages are defined as the ratio between total compensation and the number of hours worked. With the exception of I_t, for which we apply the gross capital formation price index, all other quantities (C_t, w_t) are converted into real variables using the GDP deflator. To account for the model-based market clearing condition for output, we assign an empirical measure of the latter as $Y_t = C_t + I_t$.[34] Next, economy-wide aggregates are converted to per capita terms by dividing them by the working age population, aged 16 and over. Since official measurements were not available for the whole sample period, the population series were transformed into quarterly frequencies by applying linear interpolation methods.

We use the harmonised CPI-index to measure variations in the price level and the 3 month interbank interest rate to indicate the monetary policy stance in our model. These variables are first transformed into quarterly rates and then detrended by the country-specific inflation targets. In the case of the Austrian economy, the inflation target was identified with the historical mean, as the sample average was sufficiently close to the annualised 2% inflation rate targeted by the ECB. On the other hand, the persistent disinflation process that occurred in the Czech Republic during the sample period had to be taken into account. Bearing in mind the CNB's monetary policy guidelines, a measure of the Czech inflation target was constructed by fitting the central values of the target band to a quadratic trend.[35] The historical and the fitted inflation target series are displayed in the figure 3.1.

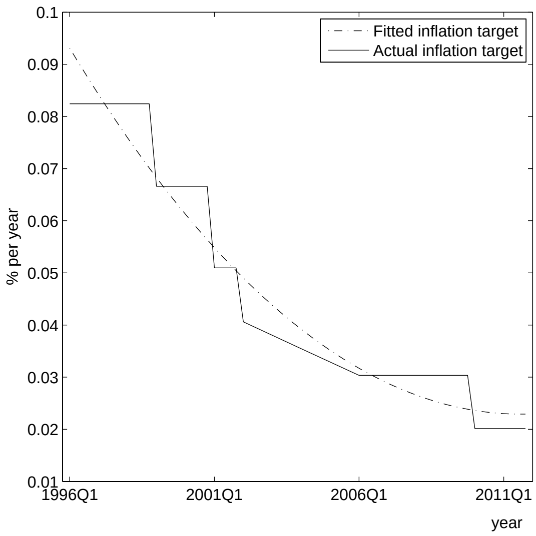


Figure 3.1: Czech Republic - inflation target

Since our model aims to explain only the cyclical features of the data, a stance had to be taken on the appropriate technique to render the output, consumption and the real wage series stationary. Following Lubik and Schorfheide (2005), Smets and Wouters (2007)

[34]See Ireland (2004a) and Fernández-Villaverde et al. (2010) for a similar mapping between the model and the empirical series.

[35]Kolasa (2009) proceeds along the same lines. For a description of the inflation targets followed by the CNB between 1998 and 2011, see http://www.cnb.cz/en/monetary_policy/inflation_targeting.html

and Rabanal and Tuesta (2010), we adopt a log-differences approach and relate y, c and w to the demeaned growth rates. International relative prices are computed based on the bilateral real effective exchange rate index (relative to the euro area), available in the Eurostat database. The variable is expressed in terms of log-deviations from a linear trend (sample mean) when the model is estimated using Czech (Austrian) data.

3.4 Baseline Estimates

3.4.1 Prior Distribution of the Parameters

Having defined the multivariate likelihood function implied by the model, we now turn to the second important step of a Bayesian analysis which concerns the assignment of prior distributions. These tools are meant to summarise the available information on a statistical phenomenon, as well as the uncertainty associated with the accuracy of this information. Owing to the difficulty of choosing appropriate statistical representations for $p(\Theta)$, the determination of prior distributions is perhaps the most difficult step involved in drawing Bayesian inferences. This is because the available information depends on the specific application and there is no "correct" way of formulating prior beliefs.[36] In the context of macroeconometric studies, the prior distribution typically includes all the plausible values of a parameter, with the mean/mode being centred around values upon which there is wider agreement from microeconomic studies, accumulation of past knowledge or simply from the opinions of subject-area experts. Among the general strategies of determining $p(\Theta)$ discussed extensively in Berger (1985, p.74-106), we simplify the computational complexity of our problem by matching the prior knowledge to several classes of standard parameterised distributions. Following most studies in the literature, the structural parameters are assumed to be independently distributed of each other. This convenient assumption implies that the joint prior density equals the product of the marginal densities of each component of Θ.[37] The family of statistical distributions that the marginal priors belong to are not chosen in an arbitrary manner, however. They are selected to meet various restrictions imposed by economic theory. For parameters defining the degree of nominal rigidities, nominal indexation or the persistence of structural shocks, it is common to use beta distributions. These parameterisations are very convenient, for they restrict the possible realisations of the random parameters in the $[0, 1]$ interval. On

[36] Regarding the above point, Robert (2007) notes that "there is no such thing as *the prior distribution*, except for very special cases."

[37] Del Negro and Schorfheide (2008) discuss instances when the independence assumption might not be realistic.

the other hand, the gamma distribution is useful in instances where nonnegative values have to be ruled out or there is a fundamental reason why a lower boundary should be imposed based on a theoretical argument. It is immediately apparent that the intertemporal or intratemporal elasticities of substitution, σ and θ, can have their marginal prior distribution specified in this way.

The relatively scarce empirical evidence on the Czech Republic and Austria, available in terms of past calibration exercises and econometric studies, has determined us to substitute the prior moments of some distributions with the euro area analogues. In all instances, however, we have properly documented the choice of the prior distributions in relation to other studies.[38] Despite the limitation of the prior elicitation process, the influence of the subjective input on our final conclusions regarding the business cycle synchronisation and structural alignment between the Czech Republic and Austria is less problematic. This is because identical priors were assigned to each of the structural parameters in two model-economies. Although we do not claim that such a consideration is entirely realistic, our choice can be regarded in terms of a null hypothesis which states that the two economies under investigation are *a priori* similar. By doing so, we let the data decide whether the prior belief of structural alignment is justified or not.

Similarly to other studies (i.e. Levin et al., 2006), the empirical series were not very informative about certain structural parameters which were kept fixed throughout the estimation. The necessity to calibrate some components of Θ is an immediate consequence of the data transformation procedure, which requires that stationary data be an input for the Bayesian approach. When the data is transformed, however, key information about first order moments is lost. As some parameters such as those defining the steady state $\frac{C}{Y}$ ratio critically depend on the first-order moments information input, it is very difficult to achieve full identification of Θ. An extensive discussion on this topic is presented in Hall (1996) and Guerron-Quintana and Nason (2012).

The values of all calibrated parameters are chosen in agreement with the historical averages within our sample. Specifically, we fix the discount factor at $\beta = 0.997$, which corresponds to a steady state real interest rate of 1.2 percent per year.[39] The quarterly depreciation rate of capital is set at the standard level of $\delta = 0.025$, implying that the capital stock becomes obsolete at an annual rate of 10 percent. Owing to the higher investment rates observed in the Czech data, we choose a value of the capital share in production given by $\alpha = 0.4$, as compared to 0.34 in the case of Austria. By doing so,

[38] Robert (2007) suggestly states that: "Ungrounded prior distributions produce unjustified posterior inference."

[39] If the economy is characterised by a BGP growth rate of 2 percent per year, as the data suggests, then the steady state level of the real interest rate would be equal to 3.2 percent.

we are able to match the $(\frac{I}{Y})^{cze} = 0.35$ and $(\frac{I}{Y})^{aut} = 0.3$ investment-output ratios in our sample and theoretically implied by equation (H.10). In addition to the components of

Parameter	Description	Czech Republic	Austria
(a) Calibrated parameters			
β	Discount factor	0.997	0.997
δ	Depreciation rate of capital	0.025	0.025
α	Capital share in production	0.4	0.34
υ	Share of the domestic intermediate sector	0.55	0.55
ρ	Elasticity of substitution - goods	7	7
φ	Elasticity of substitution - labour	5	5
ξ	Elasticity of the risk premium	0.0001	0.0001
(b) Implied steady state relationships			
$\frac{C}{Y}$	Consumption output ratio	0.65	0.70
$\frac{I}{Y}$	Investment output ratio	0.35	0.30

Table 3.1: Calibrated parameters

Θ describing preferences and technology, we also fix some parameters pertaining to the market structure. Specifically, we set the goods and labour elasticities (ρ, φ) at levels that entail steady state markups of 16.66 and 25 percent, respectively. These parameters have a very small effect (if any) on the endogenous propagation mechanisms within our model. Finally, we calibrate the risk premium elasticity at $\xi = 0.0001$, a value that is sufficiently low not to affect the endogenous response of the net foreign assets position.

The reader who is not interested in knowing how our prior choices relate to the previous literature can confidently skip the remaining discussion in this subsection. A comprehensive summary of all the prior assignments is presented in table 3.2 on page 148.

We formulate independent prior densities for each of the remaining twenty-eight parameters of the structural model. To keep a more transparent account on how prior distributions are assigned in each case, we group the stochastic parameters into five sets that refer to: (i) the demand-side (σ, η, θ, κ, γ and ϑ); (ii) the price setting problem (χ_w, ψ_w, χ_p and ψ_p); (iii) the monetary policy reaction function (χ_r, α_π, α_y, α_s); (iv) the shock persistence (ρ) and (v) the shock volatility (σ).

The statistical parameterisation for class (i) is discussed below. As in Smets and Wouters (2005), the coefficient of relative risk aversion (σ) is normally distributed, with a mean equal to 1 and a slightly lower standard deviation of 0.3. θ and η are assigned gamma distributions. The elasticity of substitution between domestic and foreign goods (θ) has a mean equal to 1, which corresponds to the calibration used by Gali and Monacelli (2005). The value of θ is also close to the standard estimates in the open economy literature.[40] In an early work on the Czech Republic Laxton and Pesenti (2003) set $\theta = 1.1$, whereas the more recent study of Ravenna and Natalucci (2008) analysing the same country imposes $\theta = 1.5$. On the other hand, the inverse elasticity of labour supply has a prior mean equal to 3, which is close to the calibration of 2.5 imposed by Laxton and Pesenti (2003). Owing to the wide range of plausible estimates, which lie in the [0,6] interval, the standard deviation of η is set at 0.4. Finally, κ is normally distributed, with a parameterisation that is identical to the one used by Smets and Wouters (2005) and Kolasa (2009).

The parameters belonging to sets (ii) and (iii) and γ are all restricted within the $[0, 1]$ interval. Following Adolfson et al. (2007), all these random parameters are assigned beta prior distributions. The moments characterising the density of the Calvo parameters are similar to those used by Smets and Wouters (2003, 2005) and Lubik and Schorfheide (2005), with a mean of 0.75 and a standard deviation of 0.05. In this case, a tight prior distribution is needed to obtain a proper identification of ψ_p and ψ_w. On the other hand, the standard deviation of the Calvo indexation parameters is larger, owing to a larger uncertainty regarding the empirically plausible range of values. Both the indexation and the habit persistence parameters have a mean equal to 0.7, a level that is consistent with those typically used in the literature.[41] Following Smets and Wouters (2007), the AR(1) coefficients of the shock processes are assigned a noninformative prior, which is centred at a mean equal to 0.5. The standard deviation of the shock persistence parameters is quite large (0.2) and adds only a slight curvature on the marginal distributions.

The statistical parameterisations we use for the feedback coefficients in class (iii) are similar to those in Justiniano and Preston (2010a). The policy instrument responds to deviations of inflation from target according to a gamma distributed reaction coefficient α_π. Its marginal prior is loose, having a mean of 2 and a standard deviation of 1. On the other hand, the output and real exchange rate feedback coefficients have their prior means set at 0.25 and 0.3, whereas the smoothing parameter χ_r is assigned a noninformative beta distribution. Lastly, the standard deviations of the shock processes are distributed according to inverted gamma(IG) distributions. This kernel family is a popular choice in the Bayesian literature, as it represents a conjugate prior for σ^2 in the Gaussian model when the mean is known. The IG priors have two degrees of freedom, which implies that their variance is infinite.

[40] Chari et al. (2002) survey the standard calibrations, which typically lie in the $[1, 2]$ interval.
[41] See Smets and Wouters (2003).

3.4.2 Posterior Analysis

When the prior distribution $\pi(\Theta)$ is available, the posterior kernel $\pi(\Theta|\mathbb{Y})$ can be computed according to the probability inversion principle specified by Bayes' Theorem. The updated distribution is then the extensive summary of the information available on the vector of parameters Θ, integrating simultaneously prior information and information brought by the set of observations $\mathbb{Y}_t$. Table 3.2 presents the point estimates of the mean, the mode and the 5th and 95th posterior percentiles of the marginal distribution of each parameter. All these statistics provide useful information regarding the location and the uncertainty associated with the posterior estimates. The data are quite informative on most structural parameters, whose marginal posterior kernels are more concentrated around their mean. In an estimation exercise where all parameters are well identified, one aims to obtain posterior standard deviations that are significantly lower as compared to the prior analogues. Based on the estimated inverse Hessian evaluated at the posterior mode, we find that these premises are met in our case.[42]

A visual assessment of how different the structural parameters in the two economies are can be made based on figures 3.2 and 3.3. The more the marginal posterior kernels overlap, the more evidence for individual parameter homogeneity there is. If the estimation exercise gives rise to a close correspondence between the Czech and Austrian posterior kernels, then the above interpretation is reassuring only if the posterior distributions are mostly determined by the conditional likelihood function. In contrast, an empirical finding suggesting a strong similarity between the marginal posterior kernels *and* the common prior densities would prevent an investigator from making reasonable convergence inferences. Such a situation indicates potential identification problems, as the prior density is not updated in certain dimensions of the parameter space, whereas the likelihood function is flat. Knowing whether a DSGE model suffers from identification/information failures is essential, as this condition stands as a prerequisite for drawing meaningful inference. In the presence of such pathologies. estimates may be biased, inconsistent and the use of asymptotic methods inappropriate (see Canova and Sala, 2009; Koop et al., 2011, for extensive discussions).

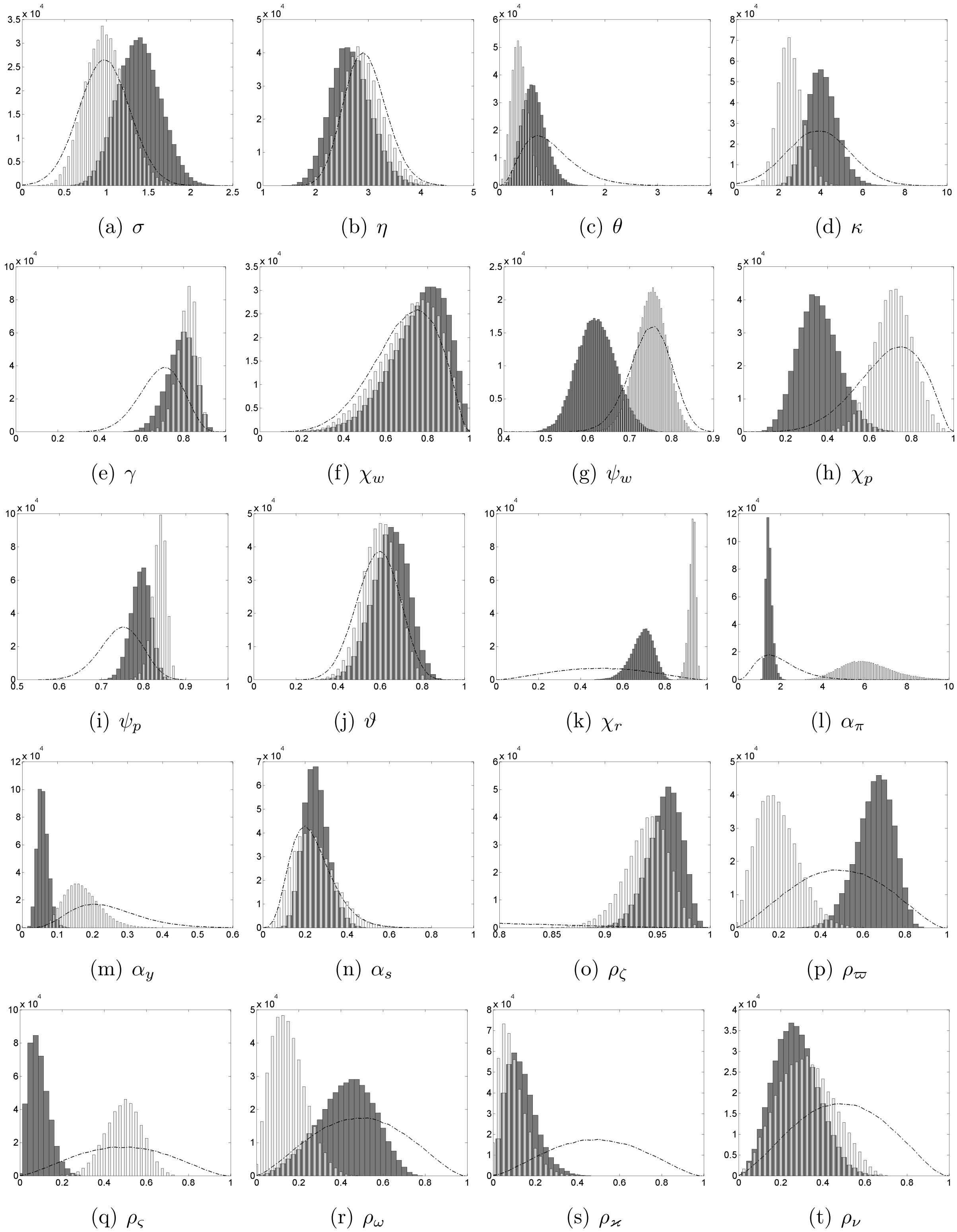
Hence, identification problems have to be taken into account when making cross-country comparisons of macroeconomic structures. Detecting such issues in applied work, however, is a very challenging task. This is because the mapping between the parameters of the DSGE model and the coefficients entering the linearised solution is highly nonlinear (Canova and Sala, 2009).

[42]The results are not reported owing to space considerations.

Parameter		Prior distribution			Posterior distribution Czech Republic			Posterior distribution Austria		
		Density	Mean	S.d./d.f.*	Mode	Mean	[5% − 95%]	Mode	Mean	[5% − 95%]
Relative risk aversion	σ	Normal	1	0.3	1.3923	1.3893	[0.9-1.89]	0.9687	1.0212	[0.61-1.43]
Elasticity of labour substitution^{-1}	η	Gamma	3	0.4	2.5450	2.6704	[1.94-3.43]	2.8280	2.9247	[2.27-3.54]
Elasticity of substitution	θ	Gamma	1	0.5	0.5684	0.6585	[0.25-1.10]	0.3719	0.4277	[0.15-0.67]
Investment adjustment cost	κ	Normal	4	1.5	3.9017	4.0738	[2.67-5.52]	2.5502	2.6746	[1.75-3.58]
Habit persistence	γ	Beta	0.7	0.1	0.7643	0.7854	[0.65-0.91]	0.8395	0.8275	[0.75-0.90]
Indexation wages	χ_w	Beta	0.7	0.15	0.8197	0.7504	[0.49-0.97]	0.7956	0.7234	[0.51-0.95]
Calvo wages	ψ_w	Beta	0.75	0.05	0.6067	0.6209	[0.53-0.71]	0.7509	0.7513	[0.69-0.81]
Indexation prices	χ_p	Beta	0.7	0.15	0.3363	0.3567	[0.17-0.55]	0.7279	0.7239	[0.58-0.88]
Calvo prices	ψ_p	Beta	0.75	0.05	0.7904	0.7919	[0.75-0.84]	0.8446	0.8411	[0.81-0.87]
Foreign elasticity of demand	ϑ	Beta	0.6	0.1	0.6607	0.6455	[0.47-0.81]	0.6324	0.6109	[0.48-0.75]
Interest rate smoothing	χ_r	Beta	0.5	0.2	0.6924	0.6919	[0.58-0.79]	0.9346	0.9334	[0.91-0.96]
Inflation feedback coefficient	α_π	Gamma	2	1	1.4272	1.4687	[1.2-1.78]	5.2407	6.1837	[4.16-8.18]
Output feedback coefficient	α_y	Gamma	0.25	0.1	0.0543	0.0588	[0.03-0.09]	0.1570	0.1759	[0.09-0.26]
RS feedback coefficient	α_s	Gamma	0.25	0.1	0.2515	0.2532	[0.14-0.37]	0.2223	0.2600	[0.10-0.42]
ρ technology shock	ρ_ζ	Beta	0.5	0.2	0.9655	0.9562	[0.92-0.99]	0.9516	0.9389	[0.91-0.98]
ρ preference shock	ρ_ϖ	Beta	0.5	0.2	0.6983	0.6517	[0.47-0.82]	0.1670	0.2111	[0.05-0.36]
ρ labour supply shock	ρ_ς	Beta	0.5	0.2	0.0709	0.0913	[0.01-0.18]	0.5423	0.5039	[0.36-0.65]
ρ risk premium shock	ρ_ω	Beta	0.5	0.2	0.4613	0.4223	[0.15-0.67]	0.1285	0.1643	[0.03-0.29]
ρ foreign demand shock	ρ_χ	Beta	0.5	0.2	0.5596	0.5433	[0.42-0.66]	0.4792	0.4509	[0.32-0.58]
ρ investment technology shock	$\rho_\varkappa$	Beta	0.5	0.2	0.1044	0.1345	[0.02-0.27]	0.0746	0.1081	[0.01-0.20]
ρ monetary policy shock	ρ_ν	Beta	0.5	0.2	0.2558	0.2692	[0.07-0.48]	0.2888	0.3313	[0.11-0.54]
σ technology shock	σ_ζ	IGamma	0.2	2	0.0329	0.0338	[0.03-0.04]	0.0242	0.0260	[0.024-0.028]
σ preference shock	σ_ϖ	IGamma	0.2	2	0.1086	0.1329	[0.06-0.23]	0.090	0.0952	[0.059-0.130]
σ labour supply shock	σ_ς	IGamma	1	2	0.9742	1.1874	[0.53-2.06]	0.5745	0.6856	[0.32-1.06]
σ risk premium shock	σ_ω	IGamma	0.02	2	0.0074	0.0088	[0.005-0.014]	0.0037	0.0038	[0.0030-0.0046]
σ foreign demand shock	σ_χ	IGamma	0.2	2	0.0607	0.0637	[0.05-0.08]	0.0478	0.0507	[0.041-0.060]
σ investment technology shock	$\sigma_\varkappa$	IGamma	0.5	2	0.3000	0.3229	[0.22-0.43]	0.2658	0.2833	[0.20-0.37]
σ monetary policy shock	σ_ν	IGamma	0.02	2	0.0039	0.0040	[0.003-0.005]	0.0024	0.0025	[0.0024-0.0027]

* Note: for the inverted gamma distribution, the degrees of freedom are reported.

Table 3.2: The prior and posterior distributions of the structural parameters



(a) σ (b) η (c) θ (d) κ

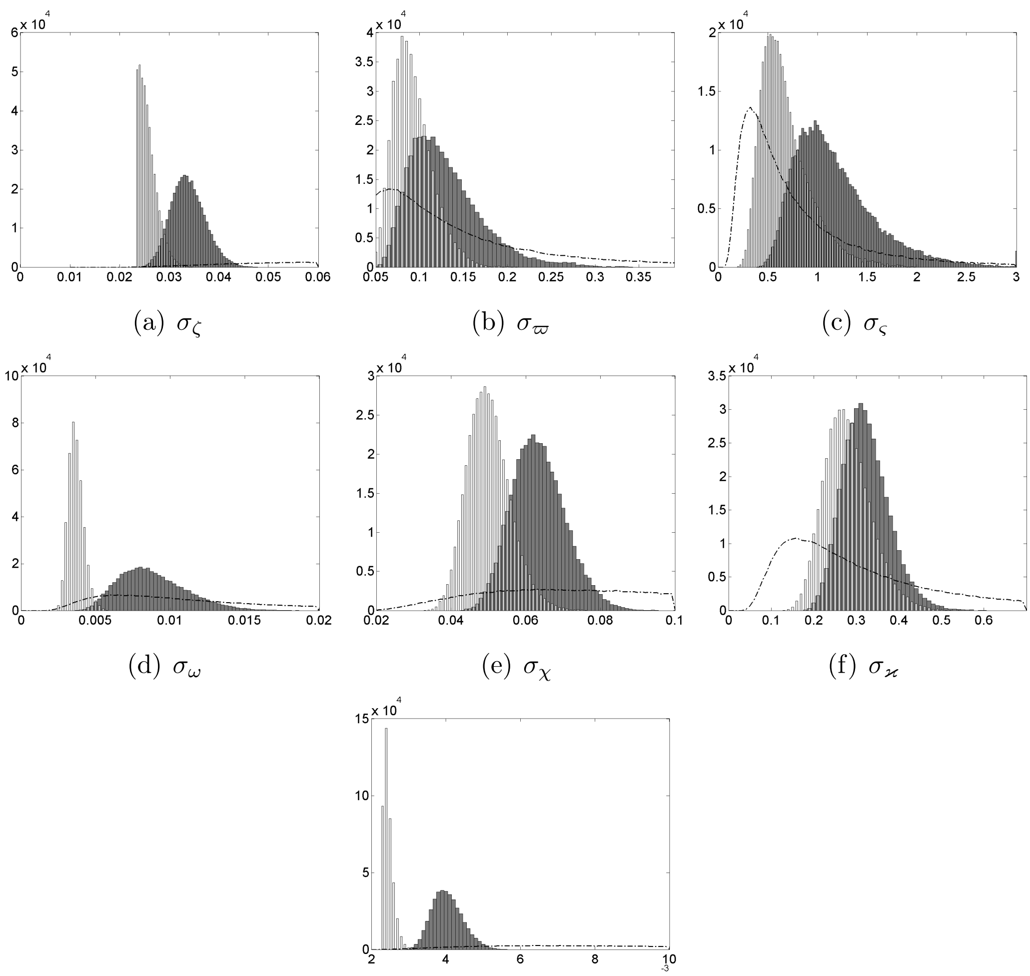
(e) γ (f) χ_w (g) ψ_w (h) χ_p

(i) ψ_p (j) ϑ (k) χ_r (l) α_π

(m) α_y (n) α_s (o) ρ_ζ (p) ρ_ϖ

(q) ρ_ς (r) ρ_ω (s) $\rho_\varkappa$ (t) ρ_ν

Figure 3.2: Estimated parameter distributions. Dashed lines are used to illustrate the prior distributions. Czech Republic posterior kernels are presented with dark shades of grey. Light shades of grey are used for Austria.



(a) σ_{ζ} (b) σ_{ϖ} (c) σ_{ς}

(d) σ_{ω} (e) σ_{χ} (f) $\sigma_{\varkappa}$

(g) σ_{ν}

Figure 3.3: Estimated shock distributions. Dashed lines are used to illustrate the prior distributions. Czech Republic posterior kernels are presented with dark shades of grey. Light shades of grey are used for Austria.

In the previous paragraph we mentioned the most common way of checking whether the likelihood function provides meaningful information on the estimated parameters, namely that of conducting prior-posterior comparisons. Although this diagnosis is necessary and generally provides strong signals that identification issues are problematic, it is by no means sufficient. In this regard, both Canova and Sala (2009) and Koop et al. (2011) mention that, even if the prior and posterior of all components of Θ are different, there is no implicit guarantee that identification problems are resolved.[43] For this reason, the recent literature went on to suggest different procedures to more thoroughly examine data-based updating failures. Particularly useful for our purposes are the local identification

[43]If prior distributions of individual parameters are independent and the posterior kernels are found to be different, identification problems may still be hidden. The main result in Koop et al. (2011) states that this can happen when the estimation procedure imposes a non-variation free parameter space.

tests developed by Iskrev (2010), which can be applied to linear Gaussian state-space models. The identification evaluation has in mind the rank of a set of Jacobian matrices, obtained by differentiating the first order moments of the observables with respect to the structural parameters. Using Iskrev's diagnoses, the analysis indicated that the Czech and Austrian models are well-identified locally and that all parameters share the desirable property.

Before investigating whether cross-country parameter differences are quantitatively significant, a task which is carried out in the next section, we first consider the interpretation of the empirical results in relation to the previous literature.

The posterior means of the Calvo parameters are estimated at $\psi_p^{cze} = 0.79$ and $\psi_p^{aut} = 0.84$, implying an average duration of price contracts somewhere in the one to two years interval. As the posterior kernels in figure 3.2 indicate, the 95% confidence regions are in agreement with most empirical estimates. In relation to the findings by Altissimo et al. (2006, p.23) for the euro area, the degree of nominal price inertia suggested in this paper is slightly larger. The above authors note that "the average duration of a consumer price spell ranges from 4 to 5 quarters, and is similar or somewhat lower for producer prices."

The posterior kernels indicate that nominal rigidities in the goods markets are predominant, as compared to those occurring in the labour market. In both Austrian and Czech cases, the average duration of nominal wage contracts is lower, as $\psi_w^{cze} = 0.62$ and $\psi_w^{aut} = 0.75$. Owing to the significant levels of the posterior means, both price and wage rigidities are important in the two economic environments. The uncertainty surrounding the posterior estimates of the Calvo parameters is different in the goods and labour markets however. Whereas price stickiness is well identified by the data with the 95% confidence regions being close to the posterior means, the posterior kernel of wage stickiness has a larger variance. In accordance with the euro area estimates in Smets and Wouters (2003), indexation of nominal contracts appears to be more important in the labour market. Our results suggest that the posterior means of indexation parameters are $\chi_w^{cze} = 0.75$ and $\chi_w^{aut} = 0.72$, as compared to $\chi_p^{cze} = 0.35$ and $\chi_p^{aut} = 0.72$. Slightly lower values are found by Adolfson et al. (2007). The cross-country levels of nominal price inertia imply that the slope of the NKPC is higher in the Czech Republic, an empirical prediction that is consistent with Jarociński (2010). This recent paper employs a Bayesian VAR methodology within a hierarchical model and offers an extensive discussion of why this might be the case. An important policy implication of the steeper NKPC in the Czech Republic is that the output costs of disinflation are lower.

Moving on to the structural estimates pertaining to the demand-side of the model, the cross-country differences stemming from the elasticities of intertemporal substitution in consumption and the inverse Frisch elasticity of labour supply are minor. In effect, this implication is in line with the findings of Kolasa (2009), who contrasts the macroeconomic structures of Poland and the euro area. Our MCMC simulations also indicate that the elasticity of substitution between domestic and foreign goods is low, with posterior means given by $\theta^{cze} = 0.66$ and $\theta^{aut} = 0.48$. This range of values is compatible with the ones in Lubik and Schorfheide (2005), who generated similar empirical predictions based on a two-country model of the United States and the euro area.

External habit formation behaviour appears to be empirically relevant in both the Czech Republic and Austria, with a posterior mode of the persistence parameter given by $\gamma^{cze} = 0.76$ and $\gamma^{aut} = 0.84$. These estimates confirm the strong evidence for consumption habit inertia in the euro area pointed out by Andrés et al. (2006). Their estimated value of γ is 0.9.[44] In contrast to the relative agreement between all the demand-side posterior kernels we mentioned until now, we find that investment adjustment costs are much larger in the Czech Republic. This prediction is quite intuitive, as investment decisions are likely to be subject to more frictions (informational constraints, less developed financial markets in terms of both deepness and liquidity) in an emerging economy.

The evidence for structural heterogeneity pertaining to monetary policy decisions is more persuasive. Whereas the cross-country estimates of the inflation feedback coefficients imply that the Taylor principle is satisfied, higher weight is attached to meeting the price stability objective by the ECB. This can be noticed by comparing $\alpha_{\pi}^{cze} = 1.47$ with $\alpha_{\pi}^{aut} = 6.18$. The Czech parameter is much better identified by the data and falls closer to the posterior mode of 1.71 reported by Adolfson et al. (2007) for the euro area. The higher uncertainty embedded in the Austrian kernel can be attributed to the simplifying assumption we made when designing our model, which presumed that ECB's monetary policy objective can be reasonably expressed in terms of stabilising business cycle fluctuations in Austria. Adolfson et al. (2007) also report a persistent smoothing behaviour by the ECB, which is reflected in a parameter value of 0.87. In our case, $\chi_r^{aut} = 0.93$, with a moderately lower feedback coefficient of $\chi_r^{cze} = 0.69$ observed for Czech Republic.

The final discussion in this section concentrates on the shock processes. A general implication of the posterior analysis is that Czech sources of business cycle fluctuations are one and a half to two times as volatile as compared to the Austrian counterparts.[45] A

[44] Adolfson et al. (2007) report a value of 0.7, Kolasa (2009) finds that the most likely realisation of the random variable for Poland is $\gamma = 0.8$, whereas the euro area estimates in Smets and Wouters (2003, 2005) suggest that the utility benefit of maintaining habits in place is given by 60% of current consumption.

[45] The results in Kolasa (2009) suggest that innovations in Poland are more than three times as volatile relative to the euro area. Given the heterogeneous specification of the prior distribution across the two-countries, the influence of subjective beliefs on the final posterior inferences should not be underestimated

higher posterior mode characterises all kernels based on Czech data in figure 3.3. As argued by Bayoumi and Eichengreen (1993, p.223), “large idiosyncratic shocks strengthen the case for policy autonomy and suggest that significant costs may be associated with its sacrifice.“ Intuitively, the larger country-specific shocks are, the more different the equilibrium adjustment under a fixed peg would be relative to the optimal response, and the higher the burden and welfare costs of maintaining euro area interest rates in place. Owing to their increased persistence and the presence of nominal rigidities, supply side disturbances are likely to lead to a more painful adjustment. Since the shock volatility ratio between the two countries is not overwhelming, we refrain from making a positive statement about its implications for the monetary integration decision until we finish all the remaining structural diagnoses. If supported by a low degree of business cycle synchronisation, this dimension of heterogeneity has to be seriously taken into account during our final recommendations.

A very intuitive finding concerns the estimated persistence of the neutral productivity shock, which displays very high values ($\rho_{\zeta}^{cze} = 0.96$ and $\rho_{\zeta}^{aut} = 0.94$). This result represents a strength of our model, as a noninformative prior distribution was assigned to this parameter. Highly persistent productivity shocks are in line with the common beliefs economists have regarding these type of disturbances, arising in the RBC literature.

In contrast, certain emerging market characteristics stand out in our posterior inferences. In particular, the inertia of preference innovations is substantially higher in the Czech Republic, a prediction that can be related to the more volatile private consumption flows (see Benczúr and Rátfai, 2010). Moreover, risk premium shocks tend to be more persistent, as the previous DSGE literature analysing currency crises in emerging markets has emphasised. For instance, Cook and Devereux (2006, p.53) note that during the East Asian Crisis of 1997-1999 “the observed risk premium shock was persistent. In fact, premiums on some long-term bonds rise by similar levels indicating a market belief that the shock would be highly persistent.” Following the more comprehensive discussion in Gertler et al. (2007), Cook and Devereux (2006) adopt a relatively high level of inertia for ω, equal to 0.95. Although we investigate a larger sample period, that encompasses both the sudden stops of the 1997-1998 and 2008 crises and the expansionary booms in the 2000’s, the posterior mode of the risk premium persistence parameter is estimated at the significant level of $\rho_{\omega}^{cze} = 0.46$. Overall, the different risk-return attitudes that international investors have towards emerging market economies can convincingly explain why changes in market sentiment towards these countries tend to last longer. Ultimately, monetary policy innovations in the Czech Republic are found to be more volatile and less persistent. A less categorical connection can be made between these estimates and the potential cred-

in this study.

ibility issues that have been associated with the implementation of monetary policy in emerging market economies. In their comprehensive discussion on this topic, Jonas and Mishkin (2004, p.355-356) note that "particularly in the Czech Republic where inflation was relatively high and rising after the fixed exchange rate regime was abandoned, the just-do-it approach to monetary policy was not seen as being potentially effective in bringing inflation expectations and actual inflation down. Without anti-inflation credibility, the just-do-it approach would not sufficiently anchor inflation expectations and persuade economic agents that monetary policy would be actually conducted to control inflation."

3.4.3 Interpreting the Evidence on Individual Parameter Convergence

While elucidating the results, little was said about the convergence implications of the observed discrepancies between individual parameters. In this section we address the comparative analysis in more detail. It is important to keep in mind that the study will only be concerned with quantifying and interpreting the benchmark support for individual parameter convergence. For the reasons outlined below, the problem of testing structural convergence hypotheses (H_0) is not addressed.

A hypothetical convergence test could investigate the restriction that a certain pair of parameters lies in the region where the marginal posterior kernels overlap. Such a statistical procedure would involve the computation of Bayes factors for the two models, by determining the marginal likelihood of the data under the null and alternative hypotheses.[46] However, the testing strategy just mentioned has its flaws. For instance, it does not consider the potentially vast regions of the parameter space that are not included in the highest posterior density intervals, but are not rejected by the data. More to the point, a restriction which states that a certain pair of converging parameters ($\Theta_k^{cze} \simeq \Theta_k^{aut}$) lies outside the domain of the marginal posterior kernel might still have a strong empirical support based on likelihood considerations. As noted by Delampady and Berger (1990), the previous observation is in fact an objection against using P-values (rather than Bayes factors) to make inferences regarding the posterior evidence against a null hypothesis. Its implication is clear: the restrictions that would have to be imposed on the two pa-

[46]The Bayes factor is a very popular tool to draw inferences under the Bayesian methodology, being equal to: $BF = \frac{p(\mathbb{Y}|H_1)}{p(\mathbb{Y}|H_0)} = \frac{\int_{\Theta_k} p(\mathbb{Y}|\Theta_k,H_1)\pi(\Theta_k|H_1)d\Theta_k}{\int_{\Theta_k} p(\mathbb{Y}|\Theta_k,H_0)\pi(\Theta_k|H_0)d\Theta_k}$.Kass and Raftery (1995) offer a comprehensive discussion of the procedures available to compute Bayes factors, using both Laplace's asymptotic approximation and Monte Carlo numerical integration methods (see also Geweke (1989) and Robert (2007, ch.7)).

rameter spaces and that are compatible with H_0 can hardly be elucidated. Hence, the essential reason why convergence tests are not addressed in this study is because the very formulation of a structural convergence hypothesis is impossible.[47]

In light of the above limitations, we will only be concerned with interpreting the convergence evidence provided by the marginal posterior kernels in the two economies. Before proceeding, however, it is important to define what is meant by structural convergence and how the concept is measured. How should the evidence be interpreted to conclude that a parameter has converged "more" as compared to others?

Since the notions of convergence and parameter proximity are closely interrelated, an assessment of parameter homogeneity should be based on an underlying metric. When the compared parameters are random (as it happens in the Bayesian methodology), however, it is not obvious what type of metric is appropriate for making convergence statements. On the one hand, an investigator might state that a large overlap between the marginal posterior kernels determines more substantial evidence for parameter homogeneity. Hence, a first metric that can be employed concerns the distance between two random parameter distributions, measured in terms of the size of the area in which the posterior kernels overlap. In what follows, this metric will be referred to by histogram intersection (HI). While certainly being useful, as it closely parallels the concept of convergence in distribution from probability theory, the HI definition of structural convergence certainly has its limitations. Think only of a situation when marginal densities are relatively flat and random draws from these kernels can have a wide range of dispersed values. Given the possibility that actual realisations of the compared parameters might be far away from each other, the case for convergence could be rather weak. Thus, the uncertainty surrounding the posterior estimates also has to be taken into account. Given the limitations of the HI measure, an alternative convergence indicator could be specified in terms of the probability that random draws from the posterior kernels are reasonably close. Again, for the proximity probability (PP) measure to be properly defined, one must specify the range of values that is consistent with parameter similarity. In our case, the latter will be specified in terms of a partition of the Czech posterior kernel. Since a parameter similarity evaluation can also be perceived in terms of the relative informational cost of moving from the Czech to the Austrian marginal posterior kernels, the final indicator to be employed in the assessment is the so called K directed divergence (KD - developed by Lin (1991)). Clearly, information theoretic divergence measures should be informative on the degree of parameter heterogeneity.

[47]In contrast, the two-country model of Kolasa (2009) provides a setting where testing that bilateral parameters are equal is more accessible. In that instance, the $\Theta_k^{cze} = \Theta_k^{aut}$ condition would be part of the restricted structural model, whose likelihood could be easily evaluated using standard methods.

In what follows, we briefly present how the complementary convergence (HI, PP) and divergence (KD) indicators are constructed. As a preliminary step, one in every 39 draws is retained from the output of the Metropolis-Hastings algorithm, resulting in two samples of $N = 10,000$ draws used for inference. For each of the 28 parameters indexed by k, the Czech posterior sample space is partitioned in $J = 7$ regions ($V_{kj}, j = 1,..,J$) of equal length. The frequencies of individual cells in the partition are summarised within the vector $n_k^{cze} = (n_{k1}^{cze}, \ldots, n_{kJ}^{cze})'$, with $\sum_{j=1}^{J} n_{kj}^{cze} = N$. Furthermore, let the probability that a random draw from $p(\Theta_k^{cze}|\mathbb{Y})$ belongs to region V_{kj} be denoted by: $p_{kj}^{cze} = n_{kj}^{cze}/N$ and let $p_k^{cze} = (p_{k1}^{cze}, .., p_{kJ}^{cze})'$. Similar considerations are followed to compute the vectors n_k^{aut} and p_k^{aut}.

The definition of the indicators we use for making convergence statements are specified below. In relation to each measure of parameter similarity, we provide relevant criteria for interpreting the strength of the evidence.

Convergence Indicator	Strength of the Convergence Evidence		
	strong	moderate	weak
1. Histogram Intersection (HI)			
$HI_k = \frac{1}{N}\sum_{j=1}^{J} min(n_{kj}^{cze}, n_{kj}^{aut})$	$HI_k \geq 0.75$	$0.25 \leq HI_k < 0.75$	$HI_k < 0.25$
2. Proximity Probability (PP)			
$PP_k = \sum_{j=1}^{J} \frac{n_{kj}^{cze}}{N}\frac{n_{kj}^{aut}}{N}$	$PP_k \geq 0.25$	$0.06 \leq PP_k < 0.25$	$PP_k < 0.06$
3. K Directed Divergence (KD)			
$KD_k = \sum_{j=1}^{J} p_{kj}^{cze} \cdot \ \ln\left(\frac{p_{kj}^{cze}}{\frac{p_{kj}^{cze}}{2}+\frac{p_{kj}^{aut}}{2}}\right)$	$KD < 0.05$	$0.05 \leq KD < 0.3$	$KD \geq 0.3$

For instance, a histogram intersection with an area larger than 75% of the Czech density mass is considered an indication of strong convergence. A similar case is made if it is expected that more than half of the total number of draws of each kernel are expected to fall within corresponding cells of the Czech partition. All the remaining criteria can be explained along similar lines of reasoning.

Structural Parameters	HI	PP	KD	Shock Parameters	HI	PP	KD
γ	0.68	0.30	0.06	ρ_ζ	0.70	0.22	0.08
σ	0.50	0.16	0.21	ρ_ϖ	0.03	0	0.65
κ	0.28	0.12	0.34	ρ_ς	0.01	0	0.68
χ_w	0.91	0.25	0.01	ρ_ω	0.28	0.08	0.35
ψ_w	0.12	0.03	0.52	ρ_χ	0.55	0.17	0.18
χ_p	0.09	0.01	0.60	$\rho_\varkappa$	0.84	0.27	0.02
ψ_p	0.27	0.10	0.40	ρ_ν	0.80	0.21	0.04
η	0.75	0.26	0.04	σ_ζ	0.18	0.06	0.47
θ	0.50	0.23	0.16	σ_ϖ	0.60	0.28	0.10
ϑ	0.83	0.28	0.02	σ_ς	0.44	0.25	0.18
χ_r	0	0	0.69	σ_ω	0.12	0.08	0.47
α_π	0	0	0.69	σ_χ	0.34	0.15	0.31
α_y	0.06	0.01	0.62	$\sigma_\varkappa$	0.74	0.28	0.06
α_s	0.75	0.21	0.07	σ_ν	0.03	0	0.67

Table 3.3: The evidence on structural convergence. A quantitative assessment

We are now ready to quantify the empirical support for structural convergence, which is summarised in table 3.3. Based on the degree of similarity, the structural parameters can be grouped in the following classes:[48]

- strongly convergent: χ_w, η, ϑ, $\rho_\varkappa$, ρ_ν
- moderately convergent: γ, σ, κ, ψ_p, θ, α_s, ρ_ζ, ρ_ω, ρ_χ, σ_ϖ, σ_ς, σ_χ $\sigma_\varkappa$
- weakly/no convergent: ψ_w, χ_p, χ_r, α_π, α_y, ρ_ϖ, ρ_ς, σ_ζ, σ_ω, σ_ν

As most parameters fall within the moderately convergent category, it can generally be concluded that a moderate degree of structural convergence has been achieved by the Czech economy.

[48]Each parameter is assigned within a specific category if at least two criteria indicated a specific classification.

3.5 Model Evaluation

The development of a DSGE model represents an exploratory analysis, which critically depends on subjective inputs. Not only the assignment of prior distributions is a typical example in this sense, but so is the theoretical specification imposed on the data. Given the above uncertainties involved in the Bayesian inference process, a first critical aspect of the empirical analysis is to check whether the model provides a sound representation of the data. If inferences are conducted using an inadequate theoretical specification, then the ultimate conclusions will be unreliable and wrong. A second aspect that a rigorous Bayesian analysis must address is to elucidate the general validity of the answers it provides. As a result, it is important not only to obtain a good statistical fit, but also robust inferences across a broad class of models and prior specifications.

Based on the above premises, the reliability of the model as an empirical tool is evaluated along several dimensions. In section 3.5.1, we use a standard posterior predictive check to assess whether the Kalman filtered estimates of the observables are consistent with the actual data. The in sample fit evaluation is then complemented with a comparison between the theoretical and data-based second order moments. We then proceed by conducting an extensive sensitivity analysis of our baseline estimates. In section 3.5.2, the general validity of the results is examined with respect to various theoretical specifications, which eliminate the role played by real and nominal frictions one at a time. In doing so, we also illustrate what features of the model are empirically relevant. Finally, section 3.5.3 concludes with the inference implications of a general class of alternative priors.

3.5.1 Model Fit

We begin the evaluation by confronting the model's predictions with the data. To this end, the empirical performance of the benchmark model is judged along two dimensions. First, we investigate whether the one-step-ahead forecasts generated by the Kalman filter are close to the actual realisations of the observable variables when Θ is set at the joint posterior mode. Also used by Adolfson et al. (2007) and Kolasa (2009), the "in-sample fit" evaluation tool is presented in figure 3.4. A close examination of this graph reveals that the model has a good explanatory power of the historical data. When the observables are in levels, as it happens for nominal interest rates, inflation, hours and the real exchange rate, the Kalman filtered variables provide close estimates of the actual observations across the sample period.[49]

[49] The model predicts that a larger increase in unemployment should have occured during the 1997-1999 and the 2008 crises.

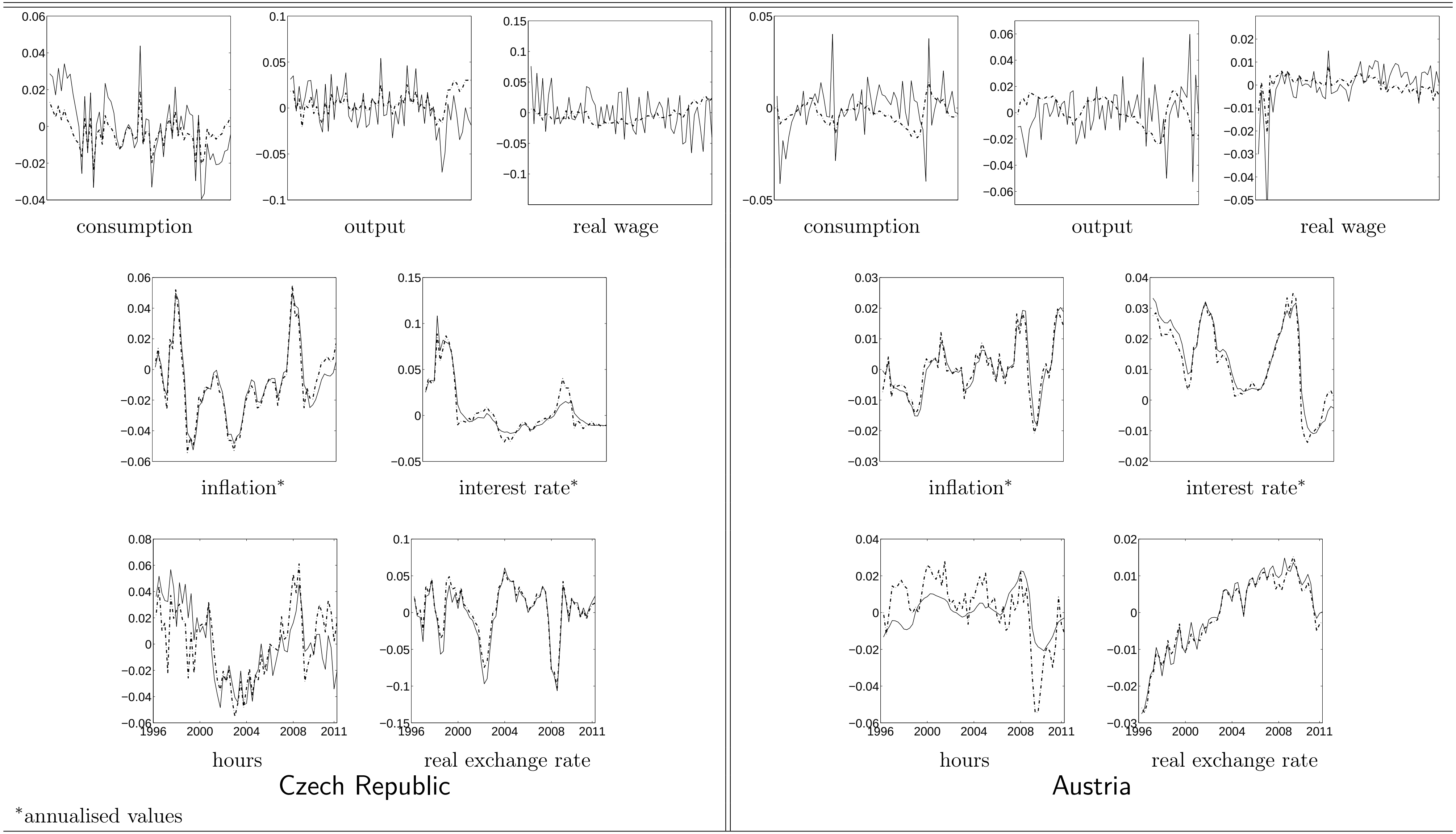


Figure 3.4: Observed variables (line) and the one-step-ahead forecasts generated by the Kalman filter (dashed).

Less convincing forecasting performance is obtained for the growth rates of consumption, output and the real wage. As it can be seen from the first three panels, the model fails to generate sufficient volatility for these variables, although it does a reasonable job at indicating the direction of next period movements. The differences between the actual realisations of the observables and the filtered estimates are particularly acute in the case of real wages. Despite these shortcomings and given its relatively small scale, the model should be considered a reliable tool for our inference purposes. Whether or not the specification we propose can be used for monetary policy analysis will depend on its out-of-sample forecast performance in relation to VAR models. This topic should constitute a good avenue for further research.

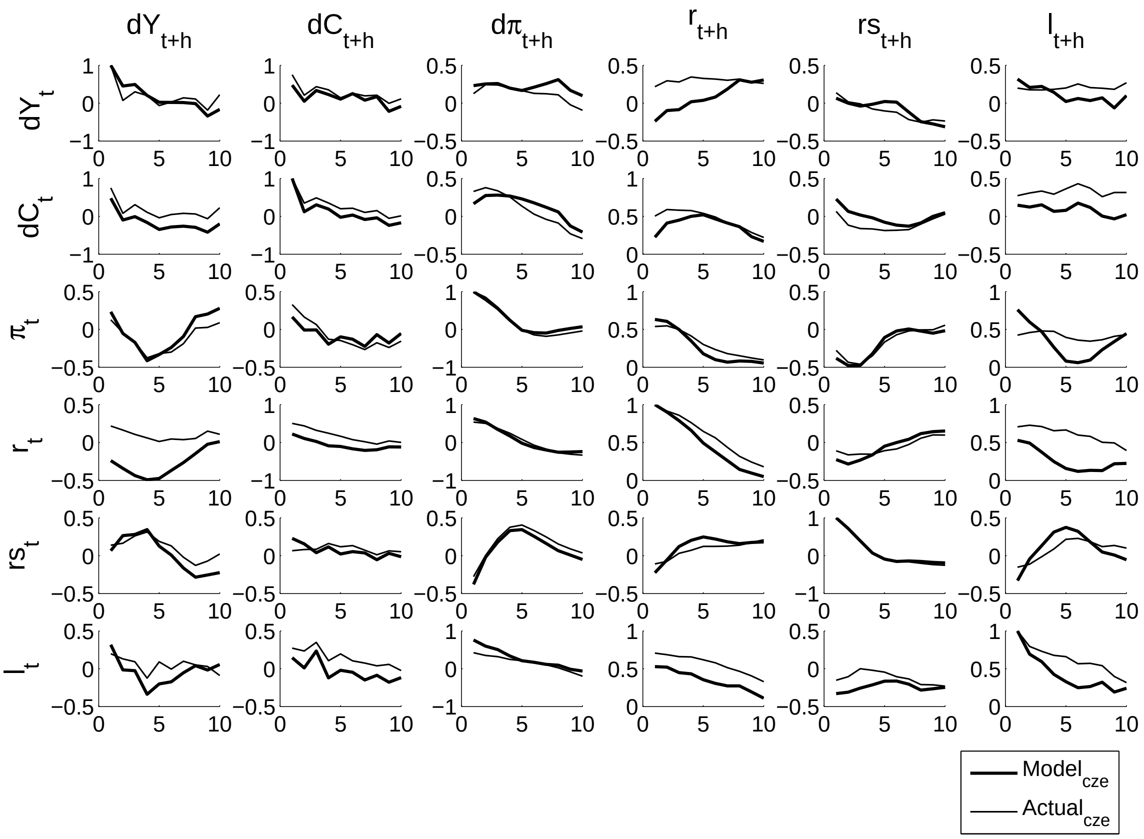


Figure 3.5: Czech Republic. Comparison between the estimated and the actual correlation coefficients of the observables, as a function of the number of lags.

The second empirical validation tool we use is represented by an RBC type of assessment. Previously employed by Fuhrer and Moore (1995), this diagnosis involves a simple comparison between the theoretical cross-correlation functions with those that arise in the data. The second-order moments are illustrated in figure 3.5. Generally speaking, it is apparent that the model also does a reasonable job at matching the estimated and the actual cross-correlation coefficients of the Czech observables. Although the empirical performance is satisfactory in most instances, we note some discrepancies for the interest rate-output growth correlation function. Also, the cross-correlation coefficient between hours and the rest of the macroeconomic variables is underpredicted at most leads and lags.

3.5.2 The Role of Frictions

Owing to the uncertainty associated with the prior distribution and the theoretical specification, it is important to have in mind that the validity of a Bayesian answer should be robust to a general class of models and prior distributions. The general principle, advocated by Berger et al. (1994), is called "Bayesian coherence". Its implications are straightforward, in that one should rarely attempt to carry on a subjective Bayesian analysis without doing appropriate robustness checks. Otherwise, the accuracy of the final conclusions might be misleading. In the sensitivity analysis that follows, we investigate whether the baseline parameter estimates are robust across a number of competing models.

Since the DSGE model developed in this chapter relies on a large number of frictions and theoretical assumptions, this exercise is also intended to provide valuable insights on their empirical relevance for explaining the data. Following Smets and Wouters (2007) and Adolfson et al. (2007), we consider six competing specifications (low price stickiness, low wage stickiness, low price indexation, low wage indexation, low habit persistence, low investment adjustment costs) that essentially switch off either a nominal or a real friction, one at the time. The results have been relegated to Appendix J, where the effects of alternative theoretical assumptions on the Czech and Austrian posterior modes are displayed in tables J.1 and J.2. To increase the ease of comparison, the baseline estimates are reproduced in the third column. The case for choosing a particular specification against another is made by computing the log data density (log marginal likelihood) using the modified harmonic mean estimator in Geweke (1999).

In relation to the Czech estimates, a reduction in the Calvo price parameter to 0.1 triggers a fall in the log data density of 22. To compensate for the lack of nominal inertia in the goods market, the optimal fit of the model gives rise to increases in the trade elasticity of substitution and in the investment adjustment costs. Also, the alternative environment is characterised by larger and more persistent monetary policy shocks and more pronounced responses to inflation. All the remaining parameters show minimal modifications. Similar conclusions hold true when nominal wage rigidities are switched off. The key difference is, however, that θ and κ are consistent with the baseline specification, whereas σ and η are updated in different directions of the parameter space. While nominal inertia represents an important friction needed to explain the data, the case for assuming nominal indexation is potentially weak. This is suggested by the low price indexation model, that has a log data density slightly larger as compared to the baseline case. Importantly, the robustness of the posterior mode estimates is remarkable when $\chi_p = 0.1$, $\chi_w = 0.1$. Similar conclusions hold true for specifications assuming the absence of real frictions. Specifically, both the low habits and low investment adjustment environments are suboptimal, as they result in a marginal likelihood deterioration of 21.7 and 53.5.

The Austrian estimates can be handled analogously and do not receive a detailed consideration. It is important to highlight some general points regarding the cross-country reliability of the baseline model. The marginal likelihood estimates give a strong indication that all frictions included in the baseline model are empirically relevant. Even if the Czech data does not reject the hypothesis of low price indexation, the empirical fit of the Austrian baseline specification is highest. As it can be noticed from table J.2, the relative marginal likelihood falls by approximately 60 when prices and wages are relatively flexible. The evidence further suggests that price indexation should be included in structural models aiming to explain Austrian business cycle fluctuations. In contrast, the likelihood based rejection of nominal wage indexation appears to be insignificant. The sensitivity checks also seem to suggest that models leaving out real frictions have less consequential effects on the empirical fit, if they are run on developed, rather than emerging, country data. The last important point involves the identifiability of η and χ_w, which was questionable under the baseline prior specification. As these parameters are more convincingly updated when different theoretical assumptions are relaxed, it is apparent that the potential information failures we mentioned before should not be a serious concern.

3.5.3 Estimates under Alternative Priors

Even though general information on the structural parameters and their plausible range of values might be available from past studies, mapping the prior knowledge into meaningful distributions is always imperfect. Owing to the uncertainty involved in the prior assignment process and its potential influence on the final conclusions, an investigator can always be criticised on several grounds. These include, among other things, the choice of parametric classes for $p(\Theta)$, the subjectivity involved in assigning prior moments when no information is available or the potential inappropriateness of tight priors. Thus, the presence of all these uncertain prior inputs calls for a thorough check of how general the final conclusions are with respect to potentially subjective inputs.

Based on the above considerations, we consider an alternative class of priors which assigns uniform distributions on the habit persistence, nominal rigidities and indexation parameters. Since no prior information is assumed and the whole range of potential parameter values is equally plausible, the priors are noninformative. The results of this second sensitivity check are presented in table J.3.[50] Under the unrestricted maximisation of the posterior mode, however, the wage indexation parameter settled on the boundary of the prior range ($\chi_w = 1$). In this instance, unfortunately, the likelihood function is not differentiable and the Metropolis algorithm cannot be implemented. For these reasons, we decided to calibrate the problematic wage indexation parameter at 0.7, rather than 1, as the full wage indexation model resulted in an ill behaved posterior kernel.[51]

We find that our estimates are largely robust with respect to the uniform priors. In relation to the Czech parameters, the alternative distributions give rise to moderate shifts in five parameters. When the new information set is used, the posterior kernels suggest slightly lower average levels of nominal wage inertia and price indexation. The inflation feedback coefficient increases to 1.85, whereas the persistence of monetary policy shocks is lower. Lastly, labour supply shocks are found to be somewhat less volatile. All remaining parameters are characterised by a strong stability of the posterior means.

On the other hand, Austrian estimates handle the sensitivity check even better. The general agreement between the baseline and alternative prior specifications is suggested by the negligible modifications of 25 out of 27 estimated parameters. The only exceptions are represented by the inflation feedback coefficient and the standard deviation of labour supply shocks, whose mean increases to 7.06 and 0.85 respectively.

3.6 A Comparative Structural Analysis of the Czech and Austrian Economies

The previous section showed that the model constitutes a reliable tool for conducting statistical inference, with the baseline estimates being robust across a general class of alternative specifications and priors. Passing the model evaluation tests is very important, since they serve as prerequisites for conducting meaningful Bayesian analysis. Furthermore, the positive model evaluation also indicates that our baseline estimates can be relied upon with more confidence.

The concept of structural convergence is much broader than that of individual parameter similarity. Even if all Czech parameters would have been found to correspond to their

[50]See Appendix J.

[51]The marginal likelihood of the two alternative models was identical.

Austrian counterparts, the case for euro adoption might not have been fully supported. As this distinction is critical for understanding the main part of our empirical analysis, it deserves further comments.

Suppose for the sake of the argument that the individual parameter convergence hypothesis holds true. Since an identical structural model is specified for the two economies, the putative example necessarily implies that the dynamic systems respond identically to *symmetric* innovations. This is because the shock transmission mechanism would be defined in terms of the same impulse response functions (IRFs), which would represent nonlinear functions of the converging structural parameters. However, there is no implicit guarantee that the various shocks hit the compared economies contemporaneously. Even if the estimated persistence and volatility of different shocks would be similar, there might still be various filtered time series that can be reconciled with a given set of observables. Since potential stochastic asymmetries determine whether or not business cycles are subject to synchronous movements, studying the incidence of shocks is an equally important element for quantifying the macroeconomic costs of monetary integration.

Now consider the converse example, in which the filtered shocks in the two countries are identical. Finding that shocks have been historically symmetric and perfectly synchronised does not attest that the underlying properties of the stochastic variables are reflected on output or inflation. In this instance, it is differences in the structural parameters that matter, as they shape the potential divergence in the underlying shock propagation mechanisms.

It becomes clear that a rigorous structural convergence analysis should not only examine the issue of parameter homogeneity. Given the moderate degree of parameter convergence we documented before, it is important to determine if economies respond similarly to symmetric shocks. Understanding the properties of exogenous stochastic variables and their incidence on the two economies is equally important. Consequently, structural convergence should also be concerned with the notion of stochastic homogeneity, by investigating the presence of asymmetric shocks. The above premises motivate the agenda for conducting the set of theoretical experiments that follow.

In subsection 3.6.1 we study the determinants of business cycle fluctuations, by analysing what shocks are important for explaining variations in output, inflation and other key macroeconomic variables. The forecast error variance decompositions will prove useful indicators of structural asymmetries, as they signal how various shocks interact to shape business cycles both in the short and the medium run. We then address (in subsection 3.6.2) the effects that country-specific parameters have on influencing the transmission of shocks throughout the economy. The merit of the IRF analysis is to draw attention to the potential business cycle asymmetries that might arise even when shocks are common. Subsection 3.6.3 examines the historical decomposition of output and inflation. Since this empirical exercise sheds light on the key macroeconomic developments in the two economies over the past fifteen years, it will serve as an additional model evaluation tool. If the theoretical predictions prove consistent with the documented historical facts, then the model should also be validated on economic grounds. In addition, the analysis will investigate the possibility that the Czech Republic and Austria were affected by certain shocks at different moments in time. Finally, section 3.6.4 summarises the above evidence, by estimating the historical degree of business cycle correlation. Its implications for the structural alignment between the Czech Republic and Austria are then discussed.

3.6.1 Variance Decomposition

Figure 3.6 presents the forecast errors variance decomposition (FEVD) of consumption, output, interest rates, inflation, the real exchange rate and investment. Since isolating the stochastic determinants of key macroeconomic variables at different time horizons is beneficial, the estimated FEVDs are reported over a prediction period of 1, 4, 10 and 20 quarters.

In line with the Keynesian mainstream interpretation of business cycles, Czech output and consumption are mainly driven by demand shocks in the short run. As the forecast horizon becomes larger, productivity and other supply side factors become more important. Over a five year period, for example, productivity shocks account for 29% and 44% of the unanticipated output fluctuations in the two economies.[52] Of course, the asymmetry between the temporary effects of demand-side disturbances and the more persistent/permanent effects of productivity shocks on output and prices is well understood by macroeconomists, being commonly used as an identifying restriction in the SVAR methodology (see Bayoumi and Eichengreen, 1993). In contrast, cyclical variations in Austrian output are induced to a larger extent by monetary and investment adjustment shocks in the short run. Monetary policy shocks in both countries have a moderate influence on output and consumption. As we move from the short-run to the medium-run, the influence of monetary policy and demand side shocks is lowered and supply side factors are the key drivers of output. In particular, this observation applies very well to the Austrian data, where output is mainly determined after 20 quarters by productivity, investment and export demand shocks. In terms of the relative influence of each shock in the two

[52] Such patterns of intertemporal adjustment of the forecast error variance decomposition of output are also observed by Smets and Wouters (2005) for the euro area.

economies, our results indicate that demand side adjustments are more important in the Czech Republic. Whereas output is driven by different factors in the two countries, the set of shocks that have a significant impact on consumption fluctuations is qualitatively similar. In all instances, business cycle fluctuations in the euro area have a minimal effect on domestic variables.

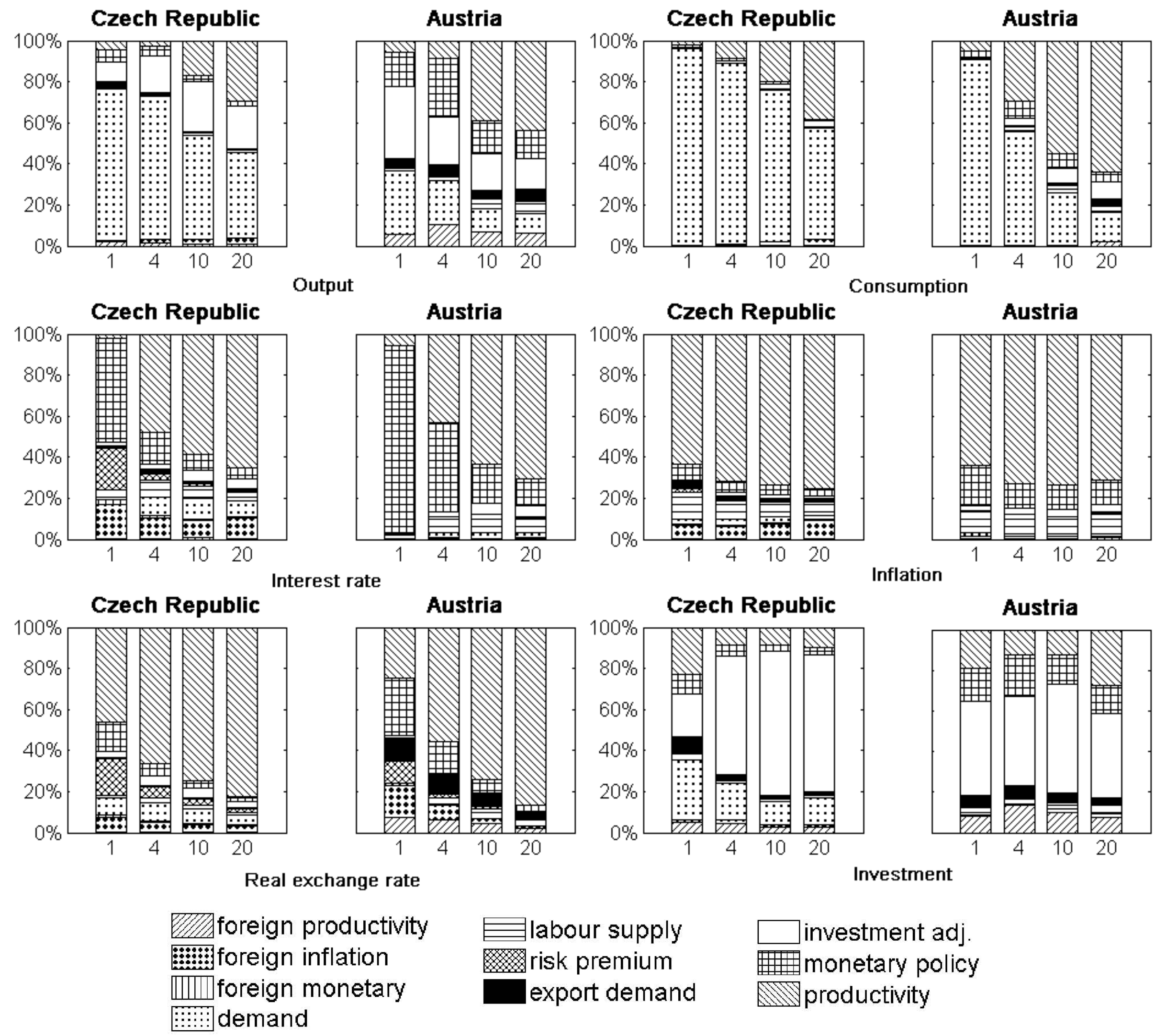


Figure 3.6: Forecast error variance decomposition (at the posterior mode)

The cross-country structural similarities are remarkable for the interest rate and inflation variables. Productivity shocks appear to be the main driver of fluctuations in both instances. A result that is in concordance with the analysis in Smets and Wouters (2005) concerns the effects on monetary policy shocks on the policy instrument. Specifically, we find that nominal shocks are the key driver of interest rates only in the short run. In light of the increasing contribution that fundamental shocks have in shaping long-term policy, the unsystematic role of monetary policy is also robust across the Austrian and Czech estimates.

The inflation FEVD is fundamentally different from the euro area estimates in Smets and Wouters (2005), however. In their study, cyclical variations in inflation are mainly induced by price markup shocks, whereas less significant sources of volatility are observed in the case of wage markup and inflation objective "structural" disturbances. All these sources of business cycle volatility do not appear in our case. However, the discrepancy between our findings and those of Smets and Wouters (2005) can be resolved by pointing out that productivity shocks take over the responsibility of becoming a supply side driver of inflation. Similarly to the consumption and output FEVDs, the influence of supply side adjustments is more significant when the forecasting interval is larger. Another interesting observation concerns the effects of foreign inflation on Czech interest rates and price dynamics, which is significantly larger as compared to the Austrian case. This effect can be intuitively attributed to the higher role played by foreign variables as drivers of business cycles in emerging economies. It also represents good evidence to infer that more attention is paid by the Czech monetary authority to monitoring foreign price dynamics, as they can fundamentally affect its ability to fulfil the CPI price stability mandate.

The final remarks involve the real exchange rate and investment forecast errors. The evidence for cross-country similarities is more mixed in this case. Even though the main drivers of real exchange rate and investment fluctuations are the same in the two countries, namely productivity and investment adjustment shocks, the relative magnitude of their influence is different. For instance, real investment in the Czech Republic is influenced more by financial frictions which give rise to an imperfect adjustment in the capital stock. As the Czech variables are more demand determined, the distinctive role played by the remaining types of shocks in the FEVDs represents an additional dimension of heterogeneity. These implications are in line with the prior beliefs a macroeconomist would have regarding the structural differences between emerging and advanced European economies.

3.6.2 Impulse Response Analysis

In this section we develop an enhanced understanding of the structural differences by looking at how symmetric shocks are propagated throughout the two economies. Studying the consequences that different posterior kernels have on the transmission mechanism of various innovations is a worthy experiment. This is because it can be used to assess whether delegating monetary authority to Frankfurt is suboptimal even if the sources of business cycle fluctuations are symmetric. Another scope of our analysis is to check whether the SVAR findings of Jarociński (2010), Anzuini and Levy (2007) and Borys et al. (2009) also hold in an estimated structural model. All these papers indicated that the transmission mechanism of monetary innovations entails remarkable similarities between Central European economies and the euro area. As we shall see, the novel implication suggested here is that the qualitative similarity does not refer only to monetary policy shocks, but encompasses quite a vast set of innovations. Finally, the comparative impulse response analysis we conduct represents an additional model-evaluation tool, as it enables us to check if the endogenous propagation mechanisms are consistent with economic theory, the results in identified VARs and the implications of other structural models.

Figures 3.7-3.10 depict the endogenous responses to four different types of orthogonal shocks. Specifically, we study how the dynamic system reacts to a standard deviation innovation in monetary policy, productivity, demand and foreign productivity. The impulse response functions are computed under the baseline set of priors.[53] Each graph distinguishes between two sets of responses, delineated with solid and dotted lines, and displays the median (thick), mean(thin) and the 95% confidence regions. All these statistics are derived based on a sample of 1000 draws from the joint posterior kernel, obtained by retaining one in every four hundred realisations of the random parameters.

We first analyse the transmission of monetary policy shocks. In the presence of imperfect nominal adjustment, a contractionary monetary policy reduces aggregate demand, which leads to lower levels of output, consumption and prices. Although our model contains a sufficient number of frictions to generate a hump shaped response of c and y, we find that their decrease is somewhat less persistent relative to the well known studies of Smets and Wouters (2003) and Adolfson et al. (2007). Even though such a fast adjustment to the downward peak can be a potential drawback of our analysis, the structural models of Boivin et al. (2008)[54] and Christiano et al. (2008) also suggest that consumption and output reach their lowest level after just 2 quarters.

[53]The initial increase in the Czech and Austrian innovations is different, as it is evaluated at the mode of different posterior kernels. Moreover, the inertia of the various shock processes we consider is country-specific. The quantitative interpretation of the IRFs should bear in mind these asymmetries.

[54]These authors compare how the euro area transmission of monetary policy shocks has changed prior to and after the introduction of the single currency. The analysis in Boivin et al. (2008) is broad and contains FAVAR and structural IRFs for a large number of euro area member states.

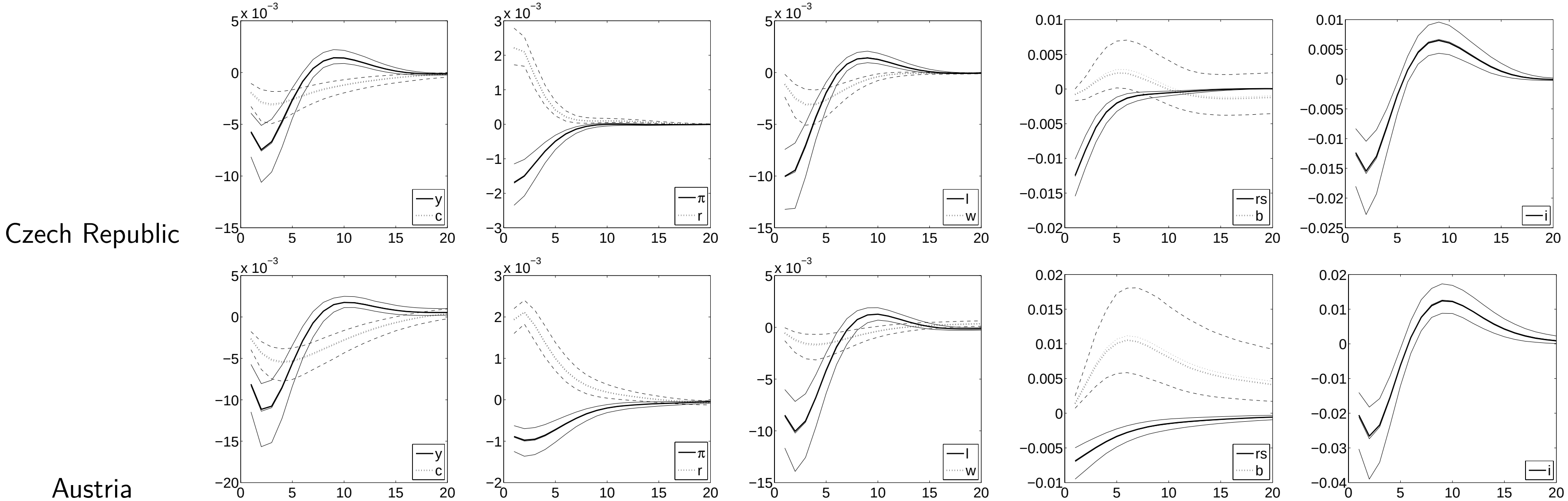


Figure 3.7: Impulse response functions to a monetary policy shock

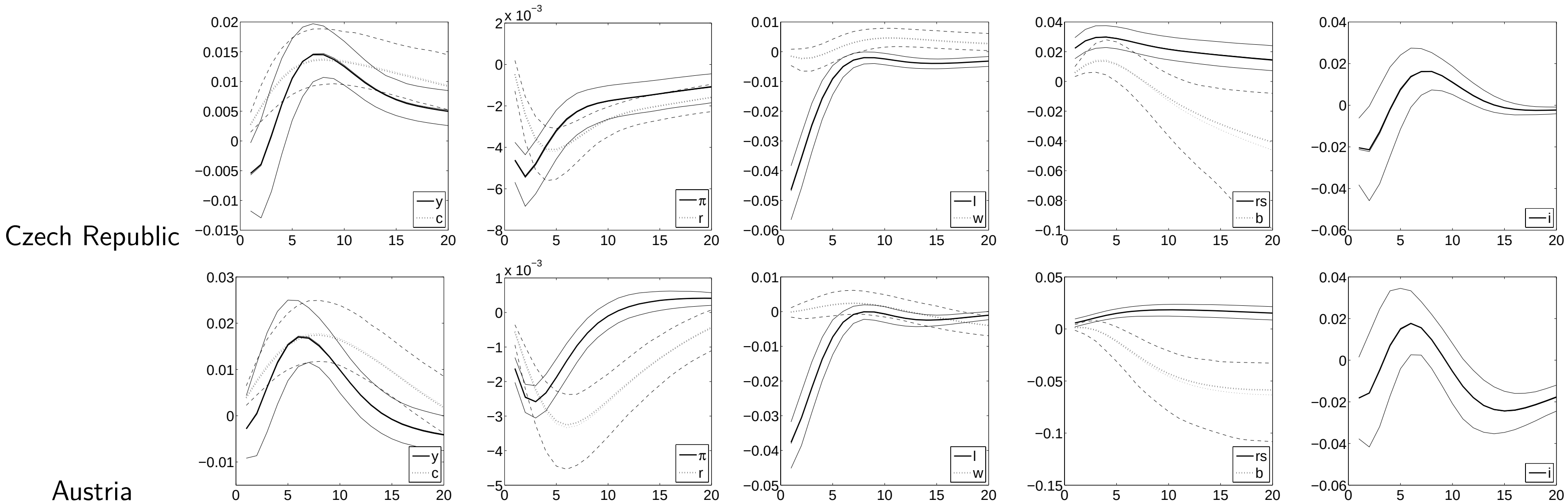


Figure 3.8: Impulse response functions to a productivity shock

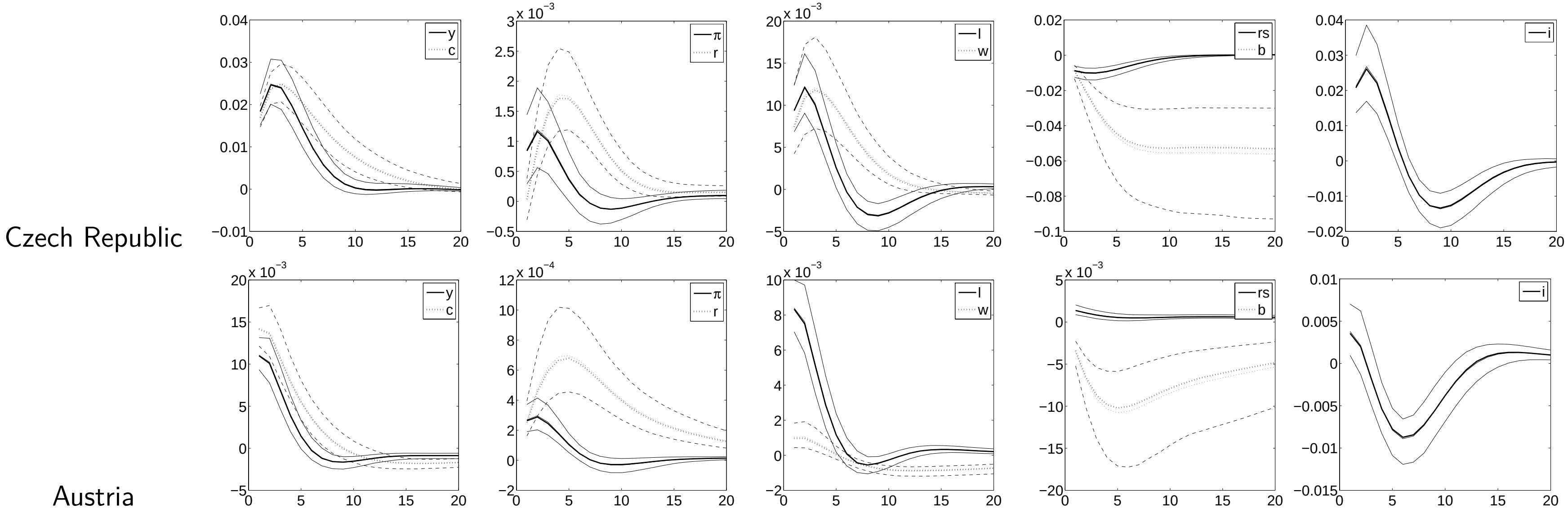


Figure 3.9: Impulse response functions to a demand shock

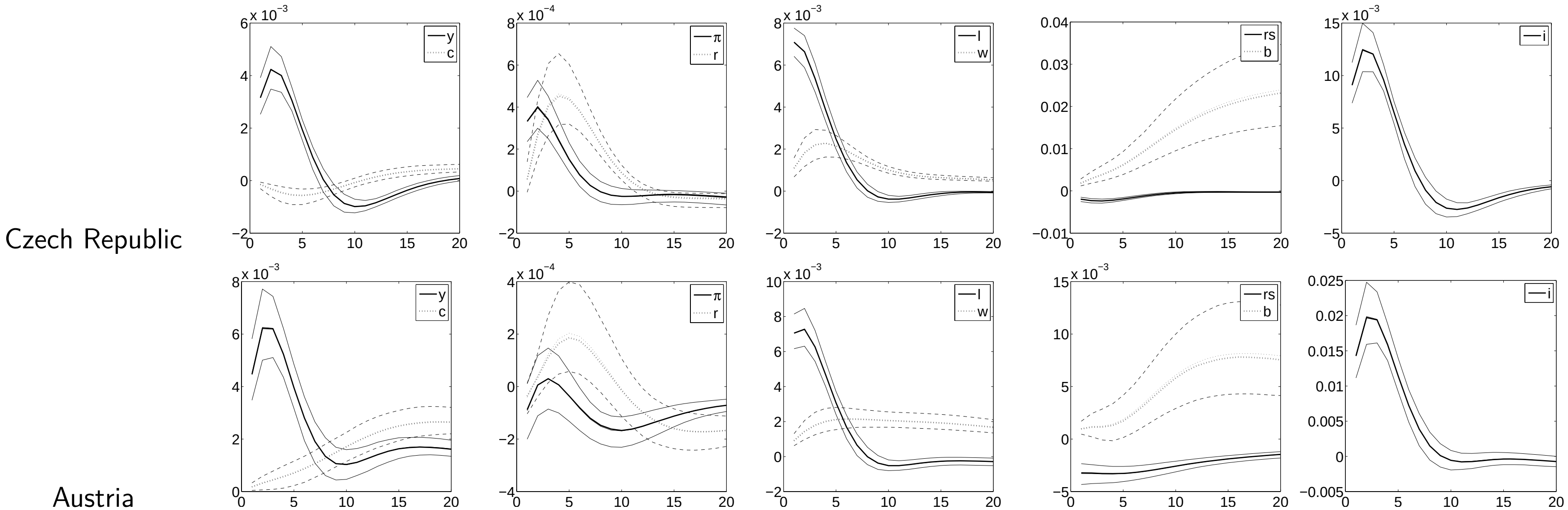


Figure 3.10: Impulse response functions to a foreign productivity shock

A more conventional implication refers to the large degree of inertia contained in the disinflation process.[55] Despite the similar adjustment path of output and consumption across the two economies, nominal interest rates and inflation are less persistent in the Czech Republic. The larger speed of adjustment can be easily understood by noticing that: (i) interest rate smoothing behaviour of the Czech monetary authority is less pronounced; (ii) the NKPC is steeper in the emerging economy.

Since less output is produced and the demand for inputs falls, both economies experience a reduction in the number of hours worked. Less definite predictions can be made regarding the real wage adjustment process. For instance, McCallum and Smets (2007) provide substantial evidence that the response of the cost of labour varies across euro area economies, being influenced by the relative levels of nominal inertia in the goods and labour markets. As a result, changes in both directions for w_t are empirically plausible. Our results suggest that nominal interest rate hikes give rise to a fall in real wages, an effect that is robust across the two economies. Also in line with McCallum and Smets (2007) is the response of investment, which is 2 to 3 times more pronounced as compared to the transition path of consumption. Lastly, the real exchange rate appreciates (more persistently in the Austrian case) and the economy experiences a current account surplus.

Although the transition paths in figure 3.7 are qualitatively similar across the two countries, it should be noted that non-negligible differences do exist in some instances, even after controlling for the larger standard deviation of the Czech monetary policy shock. This study was able to point out that the speed of adjustment in the emerging economy is larger for nominal interest rates, inflation and the real exchange rate. In terms of their qualitative features, our findings confirm the SVAR evidence in Jarociński (2010), who concluded that "the impulse responses in New Member States are broadly similar to those in the euro area countries".

We now consider the effects of temporary increases in domestic productivity. The macroeconomic profession is largely divided about the effects of a technology shock on home employment, a topic that has recently generated heated debate.[56] On the one hand, the RBC school of thought has relied on various identification schemes in SVAR models (e.g.Dedola and Neri (2007), Dupor et al. (2009), Peersman and Straub (2009)) to support the view that technology shocks are expansionary and lead to an increase in employment. On the other hand, New Keynesians have questioned the validity of models without nominal rigidities following the inquisitive research by Galí (1999), whose results suggested that hours display a persistent decline following a positive productivity innovation. Sub-

[55] The persistent disinflationary effect of monetary policy shocks is in agreement with the SVAR evidence in Anzuini and Levy (2007) and Jarociński (2010).

[56] The different views are excellently summarised by Collard and Dellas (2007).

sequent studies (Galí and Rabanal, 2005, Francis and Ramey, 2005 and Basu et al., 2004) provided further support for the New Keynesian interpretation of business cycles. Altogether, this is an area of modern macroeconomics where the SVAR methodology is not robust across various identification schemes, a point that we mentioned at the beginning of this chapter. To understand why the contrasting empirical evidence generates such controversy, it is sufficient to say that if hours decline following a technology innovation, then the NK paradigm is "correct" and the responses predicted by the baseline RBC model are counterfactual. This is why titles in the literature tend to express radical views regarding the validity of one paradigm or the other (Francis and Ramey (2005) - "Is the technology driven business cycle hypothesis dead?" vs Dupor et al. (2009) - "What do technology shocks tell us about the New Keynesian paradigm?"). The good news is that theoretical models do allow sufficient room for reconciliation, as research conducted by Collard and Dellas (2007) recently showed. Their approach is to take a more balanced view by showing that the NK SVAR evidence can be reconciled with an open-economy RBC model if the elasticity of substitution between domestic and foreign goods is low. Furthermore, the NK model can also accommodate a positive correlation between technology shocks and hours for specific monetary policy rules (Galí and Rabanal, 2005).

Our estimated IRFs imply that equilibrium levels of labour and investment fall in the short-run. The explanation for lower input demand can be easily discerned. A first useful observation is to realise that a large number of frictions in our model (e.g. habit persistence, investment adjustment costs) induce a sluggish adjustment in aggregate demand. As the short-run equilibrium levels of production are determined by the latter, the expansion in output would be relatively low even if prices were flexible. If the increase in demand is smaller than the productivity gains resulting from the technology innovation, then workers would become so productive that fewer of them are needed. The presence of staggered nominal adjustment reinforces the prediction of decreased demand for labour and capital, and more so when the fraction of randomly selected firms in the Calvo model is low[57]. Given that most production decisions are made in advance in these circumstances, "firms need fewer inputs to produce this unchanged output, so they lay off workers, reduce hours and cut back on fixed investment"(Basu et al., 2004).[58] To sum up, the fall in investment and hours arises because aggregate demand has a sluggish adjustment, which is lower than the productivity gains enjoyed by firms. Consequently, firms need fewer inputs to meet the pre-set demand for their products.

[57]This is exactly what the Czech and Austrian estimates suggest, as $\psi_p^{cze} = 0.79$ and $\psi_p^{aut} = 0.85$.

[58]In addition, there is an open-economy channel emphasised by Collard and Dellas (2007) that also leads to similar effects. When the elasticity of substitution between home and foreign goods is low, a technology innovation induces a terms of trade deterioration. Similarly to the arguments in chapter 1, domestic consumers switch away from domestic products and reduce their supply of labour.

The striking result suggested by the literature is that technology shocks can bring about both contractionary and expansionary effects on output. As the above possibilities have been extensively explored by Basu et al. (2004), who provide supportive evidence to suggest that “technology shocks are contractionary on impact”, we do not discuss them further. Essential for our purposes is that the initial contraction of output in response to productivity innovations is robust across the two economies. Despite this short-term similarity, the medium run expansionary effects on consumption and output are different, being more persistent in the Czech Republic.

The inflation and interest rate adjustment paths are in line with conventional wisdom, which states that these variables experience a persistent decline. In terms of cross-country comparisons, Austrian inflation and interest rates have a relatively higher speed of adjustment with respect to the productivity shock. The fall in the monetary policy instrument triggers a mix of real exchange rate depreciation and current account deficits, that tend to be more pronounced in the Czech Republic. Lastly, the theoretical model generates the reassuring prediction that real wages are moderately procyclical (see Solon et al., 1994).

We turn to a brief explanation of the remaining IRFs. A temporary demand shock is expansionary and leads to higher levels of output, consumption and prices. Firms adjust their production by increasing their input demand. Whereas hours are persistently higher, the accumulation of capital is short-lived. This is because the expansion in domestic consumption has a crowding out effect on investment. The latter appears to be more pronounced for the Austrian data set. Owing to the increased persistence and volatility of the preference shock ς, Czech variables are characterised by more ample movements. For instance, the expansionary effects of a demand innovation are quite significant in the Czech Republic, while the Austrian output response is barely noticeable. In order to dampen the inflationary effects brought about by the increasing output gap, nominal interest rates rise in both countries. Important asymmetries pertaining to international variables are also found as a result of the larger impact that preference shocks have in explaining Czech data. On the one hand, the real exchange rate experiences a 1% appreciation on impact. On the other hand, the large inertia of the shock triggers substantial wealth effects which in turn induce domestic agents to increase the levels of foreign borrowing. In contrast, the Austrian real exchange rate depreciates and foreign borrowing is less significant.

In figure 3.10, a productivity shock affecting the euro area has positive spillovers on domestic output and consumption. In effect, foreign supply side developments trigger a fall in the price of imported goods which enables domestic firms to produce more. Increased production is also caused by the positive effects that foreign productivity has on domestic exports. Although the effects on home variables are not very high and the Czech and

Austrian adjustment mechanisms are qualitatively similar, certain differences need to be pointed out. For instance, the response of Austrian output is 1.5 times more significant and consumption has more persistent increase. The opposite holds true for nominal variables, where we find larger inflation and interest rates responses in the Czech Republic. Finally, a foreign productivity innovation leads to a real exchange rate appreciation and a current account surplus, which is robust across the Czech and Austrian datasets.

On the whole, the results indicate a striking similarity between the shock transmission mechanisms in the two economies. By referring to a broader set of innovations, the qualitative correspondence of the IRFs generalises the VAR evidence in Jarociński (2010), who only considers the effects of monetary policy innovations. As the author extensively discusses, the similar transmission mechanisms are even more intriguing in light of "the differences in financial structures and often stressed peculiarities of the transition from the centrally planned economy" (Jarociński, 2010). Although the posterior analysis conducted in this paper was able to point out several structural aspects that are different in the Czech and Austrian economies, a more comprehensive economic explanation of our results should be a fruitful area for future research. In relation to the monetary integration process, the general similarity between the shock transmission mechanisms can be nothing else but an encouraging indicator.

3.6.3 The Historical Decomposition of Output and Inflation

An evaluation of the macroeconomics costs of euro adoption should also be contingent on both the incidence of asymmetric shocks and the business cycle concurrence. In this regard, the historical decompositions we present in figures 3.11 and 3.12 will not only identify what shocks have driven output and inflation, but they will also elucidate whether business cycles have been synchronised on a historical basis. An additional benefit of the analysis is to show that the model provides sound explanations for the recent macroeconomic developements in the two countries.

3.6.3.1 Czech Republic

The Czech experience was marked by historical events of high importance, which include the emerging market crisis (1997-1998), the EU accession in 2004 and the Great Recession (2008). The structural model proves highly competent at explaining the facts.

In May 1997 the Czech Republic was confronted with a currency crisis that determined the central bank to abandon the nominal peg.[59] The monetary authority did not persevere at trying to defend the value of the national currency. Such a strategy would have been costly and potentially ineffective anyhow, as the country would have probably run out of reserves. Rather than doing so, the policy maker allowed the koruna to float and, since then, the focus of the CNB was unambiguously on achieving price stability.[60] The historical decompositions in figure 3.11 elucidate how the decisions made by the Czech monetary authority were transmitted throughout the economy. Specifically, the attempt to prevent the collapse of the koruna by raising nominal interest rates had a negative impact on Czech output and inflation. This can be seen from the white coloured bars, which characterise the effects of monetary shocks on the two variables. Also in line with the change in the exchange rate regime is our finding that monetary interventions disappeared somewhere by the end of 1997. The subsequent sample period (with the exception of the recent financial crisis) suggests that attempts to systematically influence output or inflation were rare and largely insignificant. The emerging market crisis manifested itself as a sudden-stop of foreign capital that triggered adverse financial conditions. These negative shocks are also well captured by the model, being displayed with black shades. In contrast, demand shocks were already quite significant in that period and contributed to the fast recovery of output.

On 31 March 1998 the Czech EU accession process was initiated. Faced with better economic prospects, sustained by extensive institutional and legislative reforms, the Czech Republic became an attractive location of foreign capital.[61] Noteworthy for the Central European region was the increasing presence of foreign banks, which controlled more than half of the domestic market by the year 2000.[62] In this favourable environment where liquidity constraints became less binding, the Czech economy experienced a 9 year long real convergence episode, suggested by the persistently positive productivity gains in figure 3.11. The second wave of financial globalisation offered attractive prospects for achieving more economic and financial integration. As Fabrizio et al. (2010) observe, Central European economies "embraced the opportunities of globalisation - along with its potential downsides and risks - more so than any other region". Our results indicate that during the 2000-2004 period Czech output was driven primarily by demand and productivity shocks and the loose foreign monetary conditions. Given the historically low levels of euro area interest rates, it is not surprising that foreign investors and banks contributed to a rapid credit expansion that resulted in positive demand side developments.[63] Of course, these

[59] The Czech currency crisis is analysed in Begg (1998).

[60] See Jonas and Mishkin (2004, p.359-364) for an extensive discussion.

[61] The increased presence of foreign firms was also propelled by the decision to fully liberalise the capital account. This was one of the conditions imposed upon EU accession.

[62] See De Haas and Van Lelyveld (2006) and Cerutti et al. (2007).

[63] See the comprehensive analysis in Bakker and Gulde (2010).

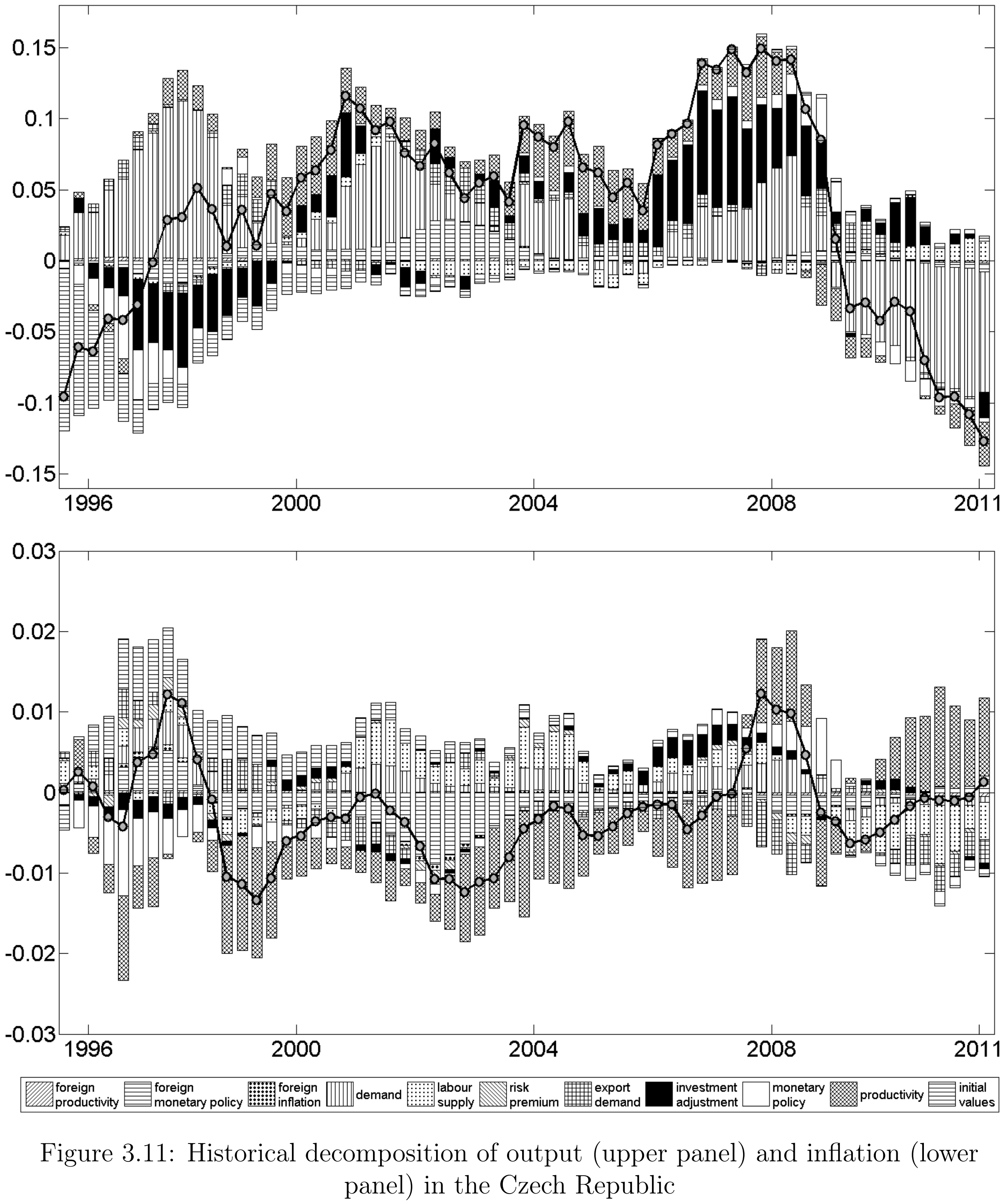


Figure 3.11: Historical decomposition of output (upper panel) and inflation (lower panel) in the Czech Republic

ideas are well known to the literature. For instance, Abiad et al. (2007) acknowledge that "with increasing financial integration, capital in Europe has travelled downhill from rich to poor countries, and has done so with gathering strength. These inflows have been associated with significant acceleration of income convergence."[64]

[64]Fabrizio et al. (2010)'s comments are also suggestive: "foreign banks (...) have been conduits of foreign capital for extensive lending to domestic businesses and households."

Another insight put forward by our analysis is the changing composition of the domestic boom determinants in 2004. Owing to increasing global imbalances, loose financial conditions and increased leverage, "the world economy was indeed entering a new more dangerous phase" by that time (Obstfeld and Rogoff, 2009). In effect, the historical decomposition suggests that Czech output was as much as 15% above trend just before the financial crisis. The unsustainability of the growth patterns and the overheating of the economy are reflected in the decomposition of output, which appears to have been driven by demand and investment technology shocks in the 2004-2008 period. These two types of innovations provide sound evidence that part of output growth was induced by building castles of sand, through relentless risk taking and credit expansion behaviour.

No wonder that the sudden stop resulted in a hard landing. Our estimate of the unexpected GDP fall in Q4-2008 is consistent with the -16% value put forward by Blanchard et al. (2010, figure 2). Notice that the liquidity crisis is suggestively identified through the disappearance of the positive investment adjustment innovations. The reversal in financial conditions also changed the direction of demand shocks, which became negative. Noteworthy are the large magnitude and the persistence of these sources of fluctuations at the end of the sample period. Our evidence also suggests that the impact of the Great Recession was augmented through negative productivity shocks. These additional adverse effects caused a further output decline from 2011 onwards. Turning to the historical decomposition of inflation, the variable appears to have been driven mostly by productivity shocks. Intuitively, the 1999-2008 expansion was characterised by large gains in TFP, which had disinflationary effects on domestic prices. Other factors that have been important sources of inflation volatility are the policy stance in the euro area and demand shocks.

3.6.3.2 Austria

In contrast to its emerging neighbour, the Austrian economy has been performing below its potential during most of the sample period. Part of the explanation for this less spectacular adjustment was the low structural flexibility of the goods and labour markets. More reforms were called for to insure an effective job creation process and that higher productivity gains would be achieved. The fall in labour market participation rates after the EU accession in 1995 also resulted in less than expected output gains relative to what Austrians were hoping for. Since the country already had the fourth largest level of GDP per capita in the European Union by that time, there was not a scope for convergence as in the Czech case. Despite these developments, Austrian growth was mostly in line with the euro area average, being robust and displaying a very low level of volatility around the balanced growth path.

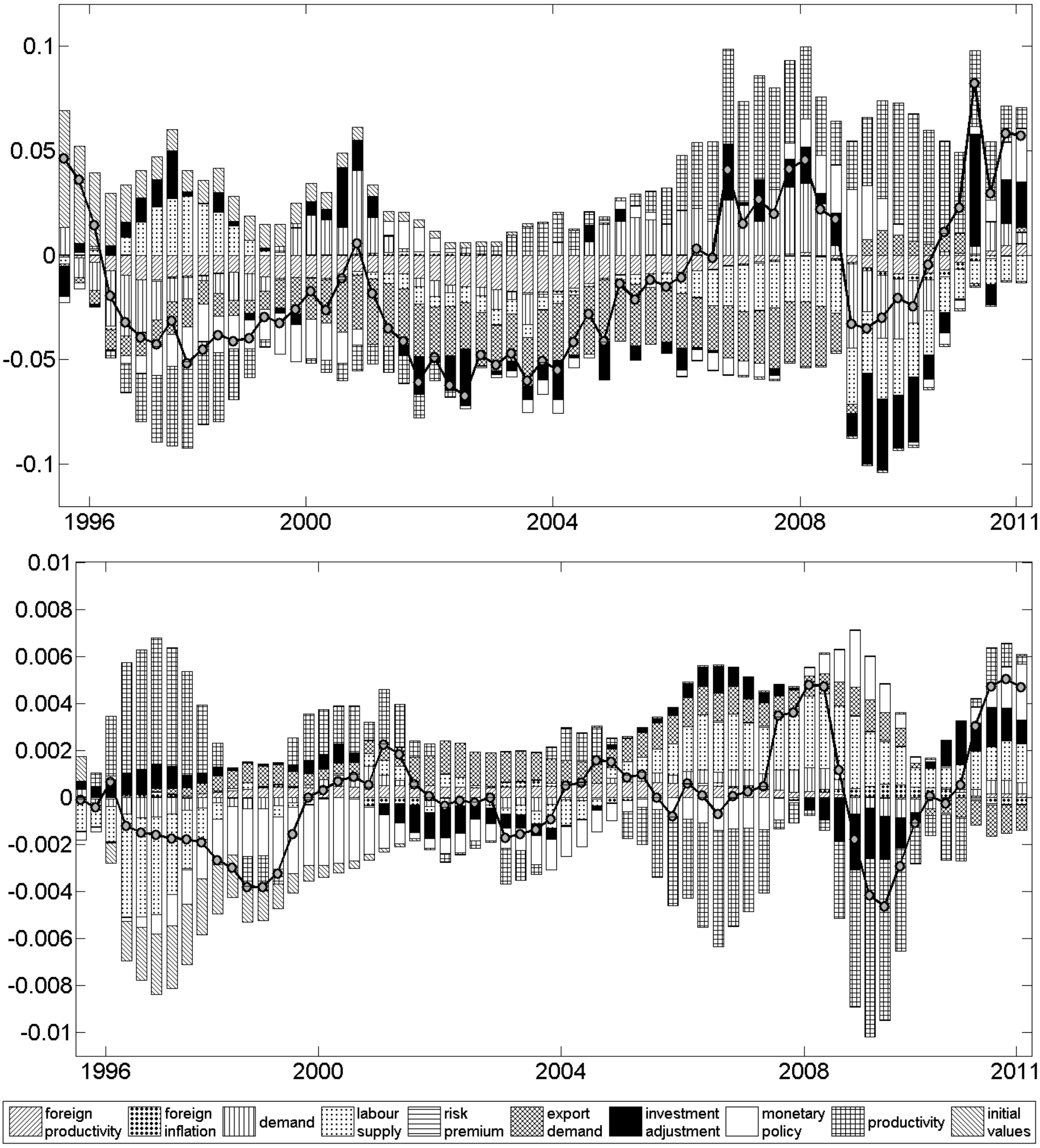


Figure 3.12: Historical decomposition of output (upper panel) and inflation (lower panel) in Austria

Our exposition of the Austrian experience is based on the OECD economic surveys written during the sample period.[65] Following the relatively weak economic performance in the late 90's, the new millennium brought about a gradual economic recovery, which was mainly caused by the accelerating rate of trade integration and increases in domestic

[65]See OECD (2009).

absorption. In particular, the tax cuts that became effective in the 2000's supported a strong growth of private consumption and an investment expansion (OECD, 2001). This episode is well illustrated by the historical decomposition in figure 3.12. Owing to the rise in uncertainty caused by the 9/11 attacks, the momentum disappeared shortly after. The resulting low levels of consumer and business confidence are reflected in the emergence of negative investment adjustment costs. In addition, the expansion in world trade was eroded and Austrian exporters experienced adverse demand shocks in foreign markets. Of particular importance in the 2001-2003 period was the lacklustre economic performance of Austria's main trading partner (Germany), whose negative effects spilled over across borders. As a result, domestic output was adversely affected.[66] On the other hand, the Eastern expansion of the European Union was very welcomed by Austrian exporters, who found new opportunities to rapidly increase their market shares in the new member states. In this sense, the persistent productivity gains that built up from 2004 are consistent with the historical evidence put forward by the OECD. As discussed in the economic surveys of the past ten years, Austria achieved the highest manufacturing productivity gains among OECD economies. Despite these positive developments in the new export markets, the economic expansion was held back by the low labour market participation rates. In this sense, the persistently negative labour supply shocks that can be observed in the 2005-2008 period are in line with the historical facts. Since the recovery had begun from a low level of capacity utilisation, investment growth was rather slow albeit the high productivity growth. In addition to productivity shocks, the increased level of output before the crisis was also sustained by a robust expansion in domestic demand. In contrast to the Czech experience, the loose financial conditions played only a limited role in fuelling domestic output gains.

Whereas the euro area continued to be the main export market for Austrian producers, its share in total exports experienced a steady decline relative to the production sold in the new member states. Moreover, the Austrian economy become more integrated in the European markets, which meant that its degree of openness and share of exports in GDP steadily increased. These empirical features are two important limitations of our DSGE modelling approach that need to be emphasised. Owing to the constant value of υ, the structural model cannot account for the faster increase in domestic exports relative to the rest of the economy. Second, only euro area macroeconomic developments can be explained by the foreign block of the model. As a result of the above limitations, the historical decomposition counterfactually implies that export demand shocks in the 2004-2008 period were negative.

[66]See the effects of negative foreign productivity shocks.

Particularly important, the downturn caused by the 2008 financial crisis was relatively moderate. In terms of the shock incidence, the recession was brought about by the cumulative adverse effects of financial stress, the reduction in the number of hours worked and detrimental demand conditions. Although all these sources of fluctuations had a substantial magnitude, their incidence was relatively short-lived, lasting for about one year and a half. As productivity gains displayed a much stronger level of persistence, the output recovery was very fast. Noteworthy as positive drivers of output in the (post) crisis period are also the monetary policy interventions by the ECB between 2007 and 2009 and in 2011. The end of the sample period is marked by a resurgence in investor and consumer sentiments, which resulted in positive investment adjustment and demand shocks.

The second panel in figure 3.12 suggests that inflation was driven mostly by productivity and monetary policy shocks. In addition, the stagnation of the 2001-2003 period and the Great Recession indicate that investment adjustment shocks were important drivers of inflation during periods of financial stress. The historical decomposition also suggests that labour supply innovations are emerging as an important source of inflation volatility. These shocks became more substantial following the Eastern enlargement in 2004.

By contrasting the decomposition of output and inflation in the two economies, it is clear that the cyclical synchronisation was historically low. The essential finding which is relevant to the monetary integration decision is that productivity shocks were asymmetric and negatively correlated. Whereas the Czech economy experienced a persistent boom in the 2000's, Austrian output was dragged down as a result of adverse international conditions. Moreover, when the advanced economy emerged from a long period of low growth and productivity gains started to build up, the Czech Republic was already overheating owing to loose financial conditions. Finally, the financial crisis had completely different effects on the two-countries. Austria managed to quickly recover. In contrast, the landing in the Czech Republic was very severe and continued to be important at the end of the sample period.

3.6.4 The Historical Correlation of Business Cycles

A comparative business cycle analysis should be concerned not with the concurrence of output and inflation fluctuations, but also with the incidence and correlation of shocks. One advantage of the Kalman filter algorithm is that it can be used to generate recursive forecasts of the unobservable shock processes. In this section, we use the in-sample estimates of these latent variables to analyse the historical correlation of the sources of business cycle fluctuations. The latter is computed based on the one-step-ahead filtered disturbances, determined when all parameters are evaluated at the posterior mode.

To assess whether idiosyncratic shocks have been important in the Czech Republic, the simple correlation coefficient is used. The results of this alternative structural convergence diagnosis are illustrated in table 3.4. Notice that the design of the table takes into account that quarterly data tend to be noisier as compared to the yearly averages. For this reason, both measures of business cycle synchronisation are reported. Furthermore, we investigate the effects triggered by the EU membership in 2004 by providing separate estimates for the pre-accession and post-accession periods. These are reflected in the second and third columns in the table.

Shock type	1996-2011		1996-2004		2004-2011	
	quarterly	annual	quarterly	annual	quarterly	annual
Productivity	-0.58	-0.67	0.14	0.19	-0.46	-0.60
Demand	-0.02	-0.07	-0.11	-0.30	0.31	0.58
Monetary policy	0.39	0.44	0.21	0.38	0.47	0.19
Investment adj.	-0.11	-0.65	0.01	-0.40	-0.08	-0.75
Labour supply	-0.26	-0.60	0.02	-0.001	-0.26	-0.73
Export demand	0.17	0.10	0.38	0.35	0.44	0.47
Risk premium	0.09	0.26	0.14	0.54	0.06	-0.02

Table 3.4: The contemporaneous correlation between the Czech and Austrian innovations. Estimated historical average and the effects of EU accession

In relation to the prospective costs of losing monetary autonomy in the Czech Republic, the implications of the shock synchronisation indicators are dismal. Specifically, we find that country-specific productivity shocks (which are likely to generate the most painful adjustment if the country decides to join the monetary union) have been negatively correlated in the sample period. The estimated cross-correlation coefficients lie between -0.58 and -0.67 and suggest that EU accession led to more country-specific supply side adjustments. Although significant quantitative differences are observed across the annual and quarterly estimates, we find that productivity, investment adjustment and labour supply shocks have been negatively correlated with the Austrian counterparts both in the 1996-2011 period and after the EU accession. The lack of synchronicity in the incidence of productivity shocks is consistent with the SVAR findings of Fidrmuc and Korhonen (2003). Süppel (2003) also noticed a weak correlation of supply-side innovations in an earlier Czech-euro area comparison.

In contrast, we find that demand side disturbances have been moderately correlated, at least in the 2004-2011 period. High levels of business cycle synchronisation are noticeable for export demand shocks, which suggests that firms in these countries have exposure to the same foreign markets. The EU accession decision seems to have contributed to more interdependence of the monetary and goods markets. In this sense, our results indicate a 0.4 increase in the synchronisation of demand innovations after 2004. Furthermore, the evidence presented in table 3.4 suggests that monetary policy interventions have become more correlated. Despite the positive developments mentioned above, the lack of synchronisation of supply shocks makes the case for monetary integration particularly weak.

3.7 Conclusions

The past decade witnessed a remarkable progress in developing adequate tools for real-world policy analysis. One of the many promising achievements of the DSGE research programme is the use of Bayesian methods as a way of bringing macroeconomic models closer to reality. In this chapter, we have contributed to the growing literature by developing a small open economy model that proved adequate for studying business cycle developments in Central European economies. Motivated by the current debate on whether euro adoption is a sound decision for the Czech Republic, we used modern system based estimation techniques to study the degree of structural alignment with the euro area.

Two major themes guided our analysis. First, we estimated a large set of structural parameters and identified how plausible their posterior means are in relation to the previous literature. The cross-country comparison revealed that most parameters were not very far from each other, which led us to conclude that a moderate degree of convergence was achieved by the emerging economy. However, certain structural differences stood out, which referred both to the stochastic properties of the shock variables and a striking divergence in the way monetary policy responds to fluctuations in the two economies. Shocks affecting the Czech Republic were estimated to be one a half to two times more volatile, whereas preference innovations had a much larger persistence. Our results also indicated that both nominal and real frictions are important in explaining the data, although indexation behaviour might not necessarily lead to an improvement in the empirical fit.

The second part of this chapter developed a rigorous comparative analysis on how the differences in the estimated parameters affect the synchronisation of business cycles or the way shocks are transmitted throughout the economy. With a strong focus on the macroeconomic costs of losing monetary policy sovereignty, we employed a battery of tests to study whether the Czech economy is prepared to join the euro area. Specifically, the study highlighted what shocks drive output and inflation at different time horizons. Furthermore, the IRF analysis showed that the propagation mechanisms of different shocks were remarkably similar across two economies. While confirming previous SVAR evidence, the result is both the most significant in the chapter and the most encouraging indicator that monetary integration might not be a concern. However, this prescription is only valid if there is significant business cycle synchronisation. To this end, the historical decomposition we conducted emphasised that the requirement is far from being met by the Czech Republic on a historical basis.

Turning back to Buiter's epigraph in the beginning of this chapter, we can confidently conclude that if the one-size monetary policy corset is inflicted on the Czech economy, then the constrained adjustment is likely to be costly. This will happen, however, not because common shocks are propagated differently in the emerging country as compared to the euro area. It will mainly be the consequence of asymmetric shocks.

Main Lessons and Directions for Future Research

This thesis shed light on some of the macroeconomic implications of euro adoption in Emerging Europe, by highlighting the complex interdependence between the monetary integration decision and real convergence. The questions of research addressed different facets of the remarkable and unique transformation of Central European economies, represented by the catch-up in standards of living and the increasing degree of business cycle synchronisation with the euro area. Although these phenomena have many aspects in common, as they are triggered by economic integration and foreign technological diffusion, they will certainly play different roles in the monetary integration assessment. This complementarity has defined the research questions of the dissertation, which investigated both the challenges of EMU accession and its potential long-run disadvantages. The results in chapters 1 and 2 suggest that policymakers in Emerging Europe should be confident about their prospects of joining the euro area under real convergence. In particular, our analysis highlighted that Maastricht compliant interest rate responses can be readily engineered and that meeting the ERM-II constraints on inflation and the exchange rate does not impose a heavy constraint on the economy. Even though adopting the single currency is feasible and can be achieved at a low welfare cost, the second part of the thesis stressed that the decision is not desirable from a long-run perspective. This is because the business cycle in the Czech economy is still not sufficiently synchronised with the monetary union.

We have studied the optimal monetary policy stance under real convergence and assessed the extent upon which the tension between nominal and real convergence might represent an obstacle towards monetary integration. This theme was explored in the first two chapters, where the dissertation sought to provide new answers based on a dynamic general equilibrium model with incomplete markets and uncorrected steady-state distortions. The study contributed to the existing literature analysing optimal monetary policy in Balassa-Samuelson environments in many respects.

First, the modelling approach provided a more rigorous treatment of the methodology needed to study asymmetric productivity growth shocks in two-sector open-economy models. One nontrivial complication in this sense was represented by the model-based detrending procedure, which required that the elasticity of trade substitution be restricted to either unitary or infinite values. This important detail has been omitted in previous studies, where analysts considered parameterisations that were inconsistent with the stationarity inducing transformations. In turn, the degree of substitutability between domestic and foreign goods was an essential determinant of the trend evolution of relative prices, the magnitude of the current account dynamics and the strength of the wealth effects driving consumption responses.

Second, the study has shown that by moving from a perfect risk-sharing to an incomplete markets model, it is indeed possible to allow for an interplay between current account fluctuations and productivity driven catch-up in the Masten (2008) economy. Given that real convergence in Emerging Europe was accompanied by persistent current account deficits, our extension resulted in a better alignment with the empirical evidence. Although the adjustment scenario arising under monopolistic competition did not allow for optimal current account movements, for it triggered an essential irrelevance of the financial market structure in the model, the opposite held true when perfect competition in the traded sector was assumed. Under the baseline case, the main explanation for the lack of adjustment in the net foreign assets position was that the wealth and substitution effects shaping the intertemporal consumption plan offset each other. In turn, this feature prevented the occurrence of consumption jumps in response to the permanent income shocks that would have been expected in normal circumstances. Under the alternative real convergence adjustment, arising when perfect competition in the traded sector was assumed, the accumulation of international debt was more pronounced, with the stock of foreign government bonds reaching as much as 60% of GDP. Hence, an important contribution of the dissertation was to study alternative instances where an imperfect risk sharing model may or may not allow for foreign financing of a domestic consumption boom during periods of high growth.

Third, the research provided a unified treatment of the Ramsey plan and the equilibrium allocation arising under a general class of optimised simple rules. The assessment of what monetary policy strategies perform well under real convergence and in alternative market structures was based on an extensive welfare analysis that should provide valuable knowledge to central bankers in Emerging Europe as to how large the costs of making inappropriate policy choices might be. This unified treatment of the topic was novel and added value to previous studies that had a more limited focus. Ravenna and Natalucci (2008) studied only the effects of simple rules, whereas Masten (2008) examined only the optimal commitment policy.

Last but not least, the first part of the thesis conducted several theoretical experiments that have not been carried out before. For instance, we have analysed the welfare maximising choice of a central parity during the ERM-II period and we have quantified the welfare costs of the Maastricht-constrained optimal plan under real convergence.

As it often happens in economics, the answer to the important question of how monetary policy should respond during periods of high growth is the familiar: "It all depends". In particular, the study highlighted that policy recommendations were closely linked to the market structure in the traded sector and critically depended on the elasticity of substitution between domestic and foreign goods. The model developed in Chapter 1 was able to indicate some of the channels that complicate interest rate decisions in open-economies. Under monopolistic competition, the optimal commitment plan was shaped not only by the distortions in the goods market, which would have required a decrease in interest rates to stimulate production away from the inefficient steady-state level. When domestic and foreign goods were imperfectly substitutable, the optimal plan was also influenced by the terms of trade externality which prescribed an interest rate adjustment in the opposite direction. Owing to the above distortions in the goods and international trade markets, the optimal plan traded off conflicting incentives. The overall effect on nominal interest rates, conditional on the chosen parameterisation, was countercyclical. On the other hand, when some distortions such as the terms of trade externality were ruled out of the model, by making domestic and foreign traded goods perfectly substitutable, the optimal response resulted in a procyclical interest rate adjustment.

Despite the lack of robustness of optimal policy recommendations across the class of models considered, which should raise awareness to policy makers in thinking more deeply about what type of adjustment describes their macroeconomic environment best, certain important findings stood out. In particular, inflation targeting regimes were consistently the most appropriate policy choices, as suggested by the welfare analysis. As Walsh (2003, p. 549) notes in his book, "a good instrument rule would be one that does well in a wide range of economic models even though it might not be optimal within any one class of models." The strong case that our analysis makes for implementing inflation targeting regimes under real convergence is potentially the most significant finding in the first part of the thesis.

Additionally, the following implications of our study should encourage more extensive research:

(i) the relationship between nominal and real convergence depends not only on the structural features of the model, but also on the monetary policy regime in place.

    Optimised inflation targeting rules triggered a positive (negative) CPI differential under monopolistic (perfect) competition in the traded sector. The above predictions were reversed for fixed exchange rate regimes.

(ii) the welfare maximising choice of a central parity during the ERM-II is consistent with moderate levels of trend implied variation of relative prices.

(iii) the welfare costs of complying with the Maastricht constraints under real convergence are relatively low.

Even though our study has conveyed many important aspects of how monetary policy should be conducted during periods of high growth, the analysis remains highly stylised and certainly has its limitations. It is therefore important to emphasise in what dimensions the model put forward in the first part of the thesis represents a simplification of a real-world economy. To this end, the potential extensions we suggest below should become promising avenues for future research.

A very useful extension would be to introduce endogenous capital accumulation in the baseline model, an assumption which poses no real difficulties if capital goods are hired in competitive rental markets and the factor of production is immobile across the two sectors (as in Ravenna and Natalucci, 2008). Furthermore, the existence of investment in this alternative setup would extend the potential channels through which interest rate decisions feed through to the real economy. For instance, the countercyclical policy response we derived for the baseline case might be affected by these alternative channels. The fact that our study abstracted from (potentially distorted) investment decisions was a matter of analytical convenience. In particular, this extension would have complicated even further the complex derivation of the Ramsey problem. As a reminder, the motivation behind not considering capital accumulation in the baseline New Keynesian model is that the capital stock is largely fixed at business cycle frequencies. However, this line of reasoning does not apply here, as the transition dynamics are examined over a much longer period. This important feature also raises additional questions as to whether keeping the values of some structural parameters fixed is appropriate.

A further interesting extension would involve the introduction of stochastic fluctuations along the time varying growth path of the economy. Even though other sources of volatility are likely to have second order effects on the transition dynamics, for they have a small magnitude relative to the convergence phenomenon, their inclusion is absolutely necessary for a more realistic modelling approach. Yet, the researcher should always bear in mind that this extension will necessarily imply that consumption jumps and current account deficits are ruled out of the analysis.[67] That being said, augmenting the monopolistically competitive version of our model with stochastic elements is indeed possible and the interested researcher might examine the effects of uncertainty along the lines of Masten's(2008) approach. The set of disturbances that should lead to a more realistic analysis include

[67] Otherwise, the standard perturbation approach to solving complex DSGE models would be rendered inappropriate. As we mentioned before, projection methods can be equally applied, but the computational effort required for their implementation is likely to become unmanageable.

shocks to the foreign economy and to productivity in levels. A particularly important point that has not been touched on before in the literature is that distinguishing between permanent and stationary productivity shocks is a nontrivial signal extraction problem to real world decision makers. As a result, both central banks and consumers have to "learn about the trend", by understanding whether an observed movement in productivity is permanent or not. As far as this aspect is concerned, incorporating the above signal extraction problem as suggested by Edge et al. (2005) should definitely be included on the future research agenda.

Lastly, the model has abstracted from fiscal policy considerations, which can be regarded as complementary to the investigation. To this end, all policy implications of the first two chapters should be interpreted conditionally, as the Czech Government was assumed to run a passive fiscal policy, with a balanced budget. One reason for maintaining the focus on the monetary policy dimension of the EMU integration process was because the fiscal sustainability constraint has a low probability of becoming binding in the foreseeable future. According to the latest report by the Czech National Bank(2011), the government debt is forecast to remain at a level of around 40% of GDP until 2014. However, the fiscal implications of euro adoption and the interactions between government policies in relation to the above decision should be further explored.

In its second part, the thesis contributed to a growing macroeconometric literature advocating the use of Bayesian methods as a way of bringing DSGE models closer to the data. A rich small open-economy was developed and estimated on Czech and Austrian data sets. In turn, the theoretical representation was used to study the structural alignment between current and prospective members of the single currency area. Such structural comparisons have been carried out before, most notably between the US and euro area business cycles in Smets and Wouters (2005). However, an important novelty in our analysis is represented by its distinct empirical focus. Specifically, the study was aimed at quantifying the stabilisation costs of Emerging European economies if they decided to delegate the conduct of monetary policy to the ECB on a permanent basis. We have shed light on what features of the data differentiate the two economies, by comparing the volatility of shocks, their historical incidence on output and inflation and their transmission mechanisms. Furthermore, the rigorous sensitivity analyses conducted throughout the third chapter helped us to identify the set of frictions that were empirically important and to investigate whether the posterior mode estimates of the random parameters were robust across a number of competing models. The DSGE model put forward also proved to be a reliable tool for policy analysis, in light of its promising in-sample fit evaluation.

The results in Chapter 3 suggest that structural convergence towards the euro area has certainly advanced in recent years. Particularly relevant in this sense are the findings that: (i) the cross-country differences in the random parameters were not very large; (ii) the transmission mechanisms of monetary, technology and demand shocks were remarkably similar. However, certain idiosyncratic features of the Czech Republic stood out as well. Specifically, the analysis indicated that Czech innovations were more volatile, more persistent and to a large extent country-specific. In light of these findings, the policy recommendation put forward by our analysis is that euro adoption be postponed until more business cycle synchronisation is achieved.

A Complete Set of Equilibrium Conditions

In this appendix, we summarise all the equations of the competitive allocation.

The first two relationships designate the proportional shares of aggregate consumption expenditures allocated to the purchases of the home traded and nontraded goods. The relative demand depends on the sector shares and relative prices.

$$C_{H,t} = \theta \upsilon T_t^{1-\theta} R_t^{1-\upsilon} C_t \tag{A.1}$$

$$C_{N,t} = (1-\upsilon) R_t^{-\upsilon} C_t \tag{A.2}$$

The functional form we adopt in defining preferences over consumption and leisure implies a marginal utility Λ given by:

$$\Lambda_t = \frac{1}{C_t} \tag{A.3}$$

Equation (A.4) is a standard Euler Equation, which characterises the dynamic path of consumption. It is also the main channel through which the policymaker influences the equilibrium allocation of the economy.

$$\Lambda_t = \beta(1+i_t)\frac{1}{\pi_{t+1}}\Lambda_{t+1} \tag{A.4}$$

Another important relationship is the first order condition of the consumer's problem with respect to aggregate labour, that equates the marginal rate of substitution between consumption and labour with the relative price w_t.

$$w_t = \frac{L_t^{\eta}}{\Lambda_t} \tag{A.5}$$

Since no frictions prevent the movement of employees across the economy, the total amount of hours spent in employment is equal to the sum of the labour services allocated in the two sectors:

$$L_t = L_{H,t} + L_{N,t} \tag{A.6}$$

Aggregate inflation is related to π_H and π_N by:

$$\pi_t = \pi_{H,t}^{\upsilon} \pi_{N,t}^{1-\upsilon} \left(\frac{T_t}{T_{t-1}}\right)^{(1-\theta)\upsilon} \tag{A.7}$$

The next three equations represent the definition of the T-N relative price R_t, the law of motion of the state variable R_{NH} and the definition we derived for the real exchange rate.

$$R_t = R_{NH,t} T_t^{\theta-1} \tag{A.8}$$

$$R_{NH,t} = R_{NH,t-1}\frac{\pi_{N,t}}{\pi_{H,t}} \tag{A.9}$$

$$Q_t = T_t^{\theta} R_t^{\upsilon-1} \tag{A.10}$$

Equation (A.11) designates the risk sharing equation. It serves two purposes. On the one hand, it is a channel through which domestic and foreign interest rates are related. On the other hand, it introduces a forward looking component on the adjustment path of the terms of trade.

$$\beta \frac{\Lambda_{t+1}}{\Lambda_t} \frac{1}{\pi_{t+1}} [(1+i_t^*)\Omega(.) \frac{T_{t+1}}{T_t} \frac{\pi_{H,t+1}}{\pi_{t+1}^*} - (1+i_t)] = 0 \tag{A.11}$$

The supply side of the economy features the definitions we adopt for the production functions and the real marginal costs, together with the price setting equations:

$$Y_{H,t} = \Gamma_{H,t} L_{H,t} \tag{A.12}$$

$$Y_{N,t} = \Gamma_{N,t} L_{N,t} \tag{A.13}$$

$$mc_{H,t} = w_t T_t^{1-\theta} R_t^{1-\upsilon} \frac{1}{\Gamma_{H,t}} \tag{A.14}$$

$$mc_{N,t} = w_t R_t^{-\upsilon} \frac{1}{\Gamma_{N,t}} \tag{A.15}$$

$$\phi - 1 = \phi mc_{H,t} - \psi_H \Big(\frac{\pi_{H,t}}{\pi_H} - 1\Big)\Big(\frac{\pi_{H,t}}{\pi_H}\Big) + \beta \psi_H \frac{C_t}{C_{t+1}} \frac{1}{\pi_{t+1}} \Big(\frac{\pi_{H,t+1}}{\pi_H} - 1\Big)\Big(\frac{\pi_{H,t+1}}{\pi_H}\Big) \pi_{H,t+1} \frac{Y_{H,t+1}}{Y_{H,t}} \tag{A.16}$$

$$\varphi - 1 = \varphi mc_{N,t} - \psi_N \Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)\Big(\frac{\pi_{N,t}}{\pi_N}\Big) + \beta \psi_N \frac{C_t}{C_{t+1}} \frac{1}{\pi_{t+1}} \Big(\frac{\pi_{N,t+1}}{\pi_N} - 1\Big)\Big(\frac{\pi_{N,t+1}}{\pi_N}\Big) \pi_{N,t+1} \frac{Y_{N,t+1}}{Y_{N,t}} \tag{A.17}$$

The model is closed with the market clearing conditions for the home traded and non-traded goods, the definitions of the trade balance and aggregate output, and the law of motion of the net foreign assets.

$$\Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2\Big] Y_{N,t} = C_{N,t} \tag{A.18}$$

$$\Big[1 - \frac{\psi_H}{2}\Big(\frac{\pi_{H,t}}{\pi_H} - 1\Big)^2\Big] Y_{H,t} = C_{H,t} + (1-\theta^*) T_t Y_t^* \tag{A.19}$$

$$TB_t = \frac{R_t^{\upsilon}}{R_{NH,t}} Y_t - C_t \tag{A.20}$$

$$\frac{B_t}{(1+i_t^*)\Omega(.)} = \frac{Q_t}{Q_{t-1}} \frac{1}{\pi_t^*} B_{t-1} + TB_t \tag{A.21}$$

$$Y_t = \Big[1 - \frac{\psi_H}{2}\Big(\frac{\pi_{H,t}}{\pi_H} - 1\Big)^2\Big] Y_{H,t} + R_{NH,t} \Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2\Big] Y_{N,t} \tag{A.22}$$

B Equilibrium Conditions in Stationary Variables

By dividing the set of structural equations that contain explosive variables with appropriately chosen cointegrating factors, the dynamic system can be expressed in stationary form. This equivalent representation of the equilibrium conditions constitutes the version of the model we will work with. In order to preserve the continuity of the discussion, the set of transformations performed in section 1.2.8 is reproduced below:

Allocations	Relative prices	Untransformed variables
$x_1 = \frac{X_1}{\Gamma_{H,t}}, \quad X_1 = \{C_{H,t}, Y_{H,t}, Y_t\}$	$\tau_t = \frac{\Gamma_t^*}{\Gamma_{H,t}} T_t$	$\pi_{H,t}$, $\pi_{N,t}$, π_t
$x_2 = \frac{X_2}{\Gamma_{N,t}}, \quad X_2 = \{C_{N,t}, Y_{N,t}\}$	$\rho_{nh,t} = \frac{\Gamma_{N,t}}{\Gamma_{H,t}} R_{NH,t}$	$L_{H,t}$, $L_{N,t}$, L_t
$x_3 = \frac{X_3}{\Gamma_t}, \quad X_3 = \{C_t, TB_t, B_t\}$	$\rho_t = \frac{\Gamma_{N,t}}{\Gamma_{H,t}^{\theta} \Gamma_t^{*1-\theta}} R_t$	$mc_{H,t}$, $mc_{N,t}$
$x_4 = \frac{X_4}{\Gamma_t^*}, \quad X_4 = \{Y_t^*\}$	$q_t = \frac{\Gamma_t^*}{\Gamma_t} Q_t$	
$\lambda_t = \Gamma_t \Lambda_t$	$w_t^d = \frac{w_t}{\Gamma_t}$	

List of transformations

The mapping between the nonstationary and stationary definitions of the macroeconomic variables enables us to show transparently how the new equations are obtained. On the one hand, all the static equations have an identical structure as in Appendix A, written in lowercase characters. On the other hand, the dynamic building blocks of the model contain additional growth terms which reflect the law of motion of the trend variables Γ.

$$c_{H,t} = \theta \upsilon \tau_t^{1-\theta} \rho_t^{1-\upsilon} c_t \tag{B.1}$$

$$c_{N,t} = (1-\upsilon) \rho_t^{-\upsilon} c_t \tag{B.2}$$

$$\lambda_t = \frac{1}{c_t} \tag{B.3}$$

$$\lambda_t = \frac{1}{1+g_{t+1}} \beta (1+i_t) \frac{1}{\pi_{t+1}} \lambda_{t+1} \tag{B.4}$$

$$w_t^d = \frac{l_t^\eta}{\lambda_t} \tag{B.5}$$

$$l_t = l_{H,t} + l_{N,t} \tag{B.6}$$

$$\pi_t = \left(\frac{1+g_{H,t}}{1+g^*}\right)^{(1-\theta)\upsilon} \pi_{H,t}^{\upsilon}\pi_{N,t}^{1-\upsilon}\left(\frac{\tau_t}{\tau_{t-1}}\right)^{(1-\theta)\upsilon} \tag{B.7}$$

$$\rho_t = \rho_{nh,t}\tau_t^{\theta-1} \tag{B.8}$$

$$\frac{1+g_{H,t}}{1+g_N}\rho_{nh,t} = \rho_{nh,t-1}\frac{\pi_{N,t}}{\pi_{H,t}} \tag{B.9}$$

$$q_t = \tau_t^{\theta}\rho_t^{\upsilon-1} \tag{B.10}$$

$$\beta\frac{1}{1+g_{t+1}}\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}}[(1+i_t^*)\Omega(.)\frac{1+g_{H,t+1}}{1+g^*}\frac{\tau_{t+1}}{\tau_t}\frac{\pi_{H,t+1}}{\pi_{t+1}^*} - (1+i_t)] = 0 \tag{B.11}$$

$$y_{H,t} = l_{H,t} \tag{B.12}$$

$$y_{N,t} = l_{N,t} \tag{B.13}$$

$$mc_{H,t} = w_t^d\tau_t^{1-\theta}\rho_t^{1-\upsilon} \tag{B.14}$$

$$mc_{N,t} = w_t^d\rho_t^{-\upsilon} \tag{B.15}$$

$$\phi - 1 = \phi mc_{H,t} - \psi_H\Big(\frac{\pi_{H,t}}{\pi_H}-1\Big)\Big(\frac{\pi_{H,t}}{\pi_H}\Big) + \beta\psi_H\frac{1+g_{H,t+1}}{1+g_{t+1}}\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}}\Big(\frac{\pi_{H,t+1}}{\pi_H}-1\Big)\Big(\frac{\pi_{H,t+1}}{\pi_H}\Big)\pi_{H,t+1}\frac{y_{H,t+1}}{y_{H,t}} \tag{B.16}$$

$$\varphi - 1 = \varphi mc_{N,t} - \psi_N\Big(\frac{\pi_{N,t}}{\pi_N}-1\Big)\Big(\frac{\pi_{N,t}}{\pi_N}\Big) + \beta\psi_N\frac{1+g_N}{1+g_{t+1}}\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}}\Big(\frac{\pi_{N,t+1}}{\pi_N}-1\Big)\Big(\frac{\pi_{N,t+1}}{\pi_N}\Big)\pi_{N,t+1}\frac{y_{N,t+1}}{y_{N,t}} \tag{B.17}$$

$$\left[1 - \frac{\psi_N}{2}\left(\frac{\pi_{N,t}}{\pi_N} - 1\right)^2\right]y_{N,t} = c_{N,t} \tag{B.18}$$

$$\left[1 - \frac{\psi_H}{2}\left(\frac{\pi_{H,t}}{\pi_H} - 1\right)^2\right] y_{H,t} = c_{H,t} + (1-\theta^*)\tau_t y_t^* \tag{B.19}$$

$$tb_t = \frac{\rho_t^{\upsilon}}{\rho_{nh,t}} y_t - c_t \tag{B.20}$$

$$\frac{b_t}{(1+i_t^*)\Omega(.)} = \frac{1}{1+g^*}\frac{q_t}{q_{t-1}}\frac{1}{\pi_t^*} b_{t-1} + tb_t \tag{B.21}$$

$$y_t = \left[1 - \frac{\psi_H}{2}\left(\frac{\pi_{H,t}}{\pi_H} - 1\right)^2\right] y_{H,t} + \rho_{nh,t}\left[1 - \frac{\psi_N}{2}\left(\frac{\pi_{N,t}}{\pi_N} - 1\right)^2\right] y_{N,t} \tag{B.22}$$

C The Trade Elasticity of Substitution and Model Detrending

In this appendix, we formally show what values of the trade elasticity of substitution between domestic and foreign goods allow for a model based detrending procedure. This proof is important, for it represents one of the criticisms the thesis makes with respect to the methodology in Masten (2008).

Consider a CES specification for the traded sector consumption index:

$$C_{T,t} = \Big[\theta^{\frac{1}{\zeta}}(C_{H,t})^{\frac{\zeta-1}{\zeta}} + (1-\theta)^{\frac{1}{\zeta}}(C_{F,t})^{\frac{\zeta-1}{\zeta}}\Big]^{\frac{\zeta}{\zeta-1}} \tag{C.1}$$

where the parameter ζ corresponds to the elasticity of substitution between domestic and foreign goods.

By solving a standard cost minimisation problem, the following input demand schedules are obtained:

$$C_{H,t} = \theta\Big(\frac{P_{H,t}}{P_{T,t}}\Big)^{-\zeta} C_{T,t} \tag{C.2}$$

$$C_{F,t} = (1-\theta)\Big(\frac{P_{F,t}}{P_{T,t}}\Big)^{-\zeta} C_{T,t} \tag{C.3}$$

where $P_{T,t}$ is defined as:

$$P_{T,t} = \Big[\theta P_{H,t}^{1-\zeta} + (1-\theta)P_{F,t}^{1-\zeta}\Big]^{\frac{1}{1-\zeta}} \tag{C.4}$$

The last three expressions generalise equations (1.7)-(1.9) that were obtained for a unitary value of ζ.

It is convenient to rearrange equation (C.4) as a function of the effective terms of trade ($T_t = \frac{P_{F,t}}{P_{H,t}}$):

$$P_{T,t} = P_{H,t}\Big[\theta + (1-\theta)T_t^{1-\zeta}\Big]^{\frac{1}{1-\zeta}} = P_{H,t}\ J(T_t) \tag{C.5}$$

We assume that the aggregate consumption index is still defined according to a Cobb-Douglas specification. This allows us to focus just on the effects of altering the parameter ζ on the detrending procedure.

As a result, the following conditions continue to hold :

$$C_{T,t} = \upsilon\Big(\frac{P_{T,t}}{P_t}\Big)^{-1} C_t \tag{C.6}$$

$$C_{N,t} = (1-\upsilon)\Big(\frac{P_{N,t}}{P_t}\Big)^{-1} C_t \tag{C.7}$$

$$P_t = P_{T,t}^{\upsilon} P_{N,t}^{1-\upsilon} = P_{T,t} R_t^{1-\upsilon} \tag{C.8}$$

Hence, the demand for home traded and nontraded goods can be written as:

$$C_{H,t} = \theta\upsilon\Big[J(T_t)\Big]^{\zeta} R_t^{1-\upsilon} C_t \tag{C.9}$$

$$C_{N,t} = (1-\upsilon) R_t^{-\upsilon} C_t \tag{C.10}$$

Making use of (C.5) and (C.8), the relative price R_t becomes:

$$R_t = \frac{P_{N,t}}{P_{T,t}} = \frac{P_{N,t}}{P_{H,t}}\frac{P_{H,t}}{P_{T,t}} = \frac{R_{NH,t}}{J(T_t)} \tag{C.11}$$

Furthermore, if (C.9) and (C.10) are divided, then:

$$\frac{C_{H,t}}{C_{N,t}} = \frac{\theta\upsilon}{1-\upsilon} J(T_t)^{\zeta-1} R_{NH,t} \tag{C.12}$$

The remaining step in the proof is to show that the relative price $R_{NH,t}$ continues to be cointegrated with the traded-nontraded productivity trend ratio.

Given that labour is perfectly mobile, the definition of the real marginal costs in the two sectors corresponds to equations (1.28) and (1.29) in Chapter 1:

$$mc_{H,t} = w_t\Big(\frac{P_t}{P_{H,t}}\Big)\frac{1}{\Gamma_{H,t}} = w_t J(T_t) R_t^{1-\upsilon}\frac{1}{\Gamma_{H,t}} \tag{C.13}$$

$$mc_{N,t} = w_t\Big(\frac{P_t}{P_{N,t}}\Big)\frac{1}{\Gamma_{N,t}} = w_t R_t^{-\upsilon}\frac{1}{\Gamma_{N,t}} \tag{C.14}$$

By dividing (C.13) and (C.14) and making use of (C.11), we obtain that:

$$\frac{mc_{H,t}}{mc_{N,t}} = R_{NH,t}\frac{\Gamma_{N,t}}{\Gamma_{H,t}} \tag{C.15}$$

Lastly, given that $mc_{H,t}$ and $mc_{N,t}$ are stationary variables, it follows that $R_{NH,t}$ is cointegrated with $\frac{\Gamma_{H,t}}{\Gamma_{N,t}}$.

But so is the ratio $\frac{C_{H,t}}{C_{N,t}}$ in (C.12). If the trade elasticity of substitution ζ has values that are different from unity or infinite, which are the two main cases considered in Chapter 2, then a model-based detrending procedure will not exist. □

D Organising the Equilibrium Conditions of the Competitive Allocation

We organise the set of equilibrium conditions of the competitive allocation in order to derive a minimal set of constraints that are relevant for the Ramsey problem. Specifying a smaller subset of restrictions will prove beneficial, as it will increase the tractability of the Lagrangian.

In the Lagrangian problem, the endogenous variables will be represented by the vector $y_t^v = \Big[mc_{H,t}, mc_{N,t}, l_{H,t}, l_{N,t}, c_t, \pi_{H,t}, \pi_{N,t}, \rho_{nh,t}, \tau_t, b_t\Big]$. The derivations below have two purposes. First, they provide an alternative form of the original system with fewer restrictions. Second, they show how the excluded endogenous variables can be obtained from the restricted set of equilibrium conditions.

Equations (B.15), (B.5), (B.2) and (B.18) imply a nontraded sector real marginal cost given by:

$$mc_{N,t} = \frac{(l_{H,t} + l_{N,t})^{\eta}}{(1-\upsilon)}\Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2\Big] l_{N,t} \tag{D.1}$$

Using the definition of the real marginal costs (B.14, B.15), it can be shown that the state variable $\rho_{nh,t}$ is equal to the ratio of the marginal products of labour. Since wages are equalised across the economy, the latter will be equal to the ratio of real marginal costs:

$$mc_{H,t} = \rho_{nh,t} mc_{N,t} \tag{D.2}$$

The law of motion of the relative price of nontraded goods is determined by the traded and nontraded sector inflation rates:

$$\rho_{nh,t} = \left(\frac{1+g^*}{1+g_{H,t}}\right)\frac{\pi_{N,t}}{\pi_{H,t}}\rho_{nh,t-1} \tag{D.3}$$

To express the terms of trade as a function of the restricted variable set, we derive the relative H-N consumption demand by dividing equations (B.1) and (B.2). Valued in terms of the traded good numeraire, the relative demand is a function of the sector shares in final consumption, $\frac{\theta\upsilon}{1-\upsilon}$.

$$c_{H,t} = \frac{\theta\upsilon}{1-\upsilon}\rho_{nh,t} c_{N,t}$$

We then substitute for c_H in the market clearing condition for traded goods (B.19) and rearrange for the terms of trade:

$$\tau_t = \frac{\Big[1 - \frac{\psi_H}{2}\Big(\frac{\pi_{H,t}}{\pi_H} - 1\Big)^2\Big] l_{H,t} - \frac{\theta\upsilon}{1-\upsilon}\rho_{nh,t}\Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2\Big] l_{N,t}}{(1-\theta^*)y_t^*} \tag{D.4}$$

The next step is to express aggregate consumption as an additional constraint faced by the Ramsey planner. Using (B.2), (B.8) and (B.18), c_t becomes :

$$c_t = \frac{1}{1-\upsilon}\Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2\Big] l_{N,t}\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)} \tag{D.5}$$

The last equation is not only important by itself, but it also allows us the derive a convenient representation of the price adjustment equations. If (D.5) is combined with the definition of aggregate inflation in (B.7) and the dynamic equation of ρ_{nh} (D.3), then the variable components of the stochastic discount factor will read as:

$$\begin{aligned}\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}} &= \frac{c_t}{c_{t+1}}\frac{1}{\pi_{t+1}} = \Big(\frac{\rho_{nh,t}}{\rho_{nh,t+1}}\Big)^{\upsilon}\Big(\frac{\tau_t}{\tau_{t+1}}\Big)^{\upsilon(\theta-1)}\frac{c_{N,t}}{c_{N,t+1}}\frac{1}{\pi_{t+1}} \\ &= \Big(\frac{1+g_{H,t+1}}{1+g^*}\Big)^{\upsilon}\Big(\frac{\pi_{H,t+1}}{\pi_{N,t+1}}\Big)^{\upsilon}\Big(\frac{\tau_t}{\tau_{t+1}}\Big)^{\upsilon(\theta-1)}\Big(\frac{1+g^*}{1+g_{H,t+1}}\Big)^{(1-\theta)\upsilon}\frac{1}{\pi_{H,t+1}^{\upsilon}\pi_{N,t+1}^{1-\upsilon}}\Big(\frac{\tau_t}{\tau_{t+1}}\Big)^{(1-\theta)\upsilon}\frac{c_{N,t}}{c_{N,t+1}} = \\ &= \Big(\frac{1+g_{H,t+1}}{1+g^*}\Big)^{\upsilon\theta}\frac{1}{\pi_{N,t+1}}\frac{c_{N,t}}{c_{N,t+1}}\end{aligned}$$

Substituting for $\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}}$ in (B.16), the traded sector NKPC becomes:

$$\begin{aligned}(\frac{\pi_{H,t}}{\pi_H} - 1)(\frac{\pi_{H,t}}{\pi_H}) = \beta\Big[\frac{1+g_{H,t+1}}{1+g^*}(\frac{\pi_{H,t+1}}{\pi_{N,t+1}})(\frac{\pi_{H,t+1}}{\pi_H} - 1)(\frac{\pi_{H,t+1}}{\pi_H})\frac{l_{H,t+1}}{l_{H,t}}\frac{[1 - \frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N} - 1)^2]l_{N,t}}{[1 - \frac{\psi_N}{2}(\frac{\pi_{N,t+1}}{\pi_N} - 1)^2]l_{N,t+1}}\Big] + \\ + \frac{\phi}{\psi_H}(mc_{H,t} - \frac{\phi-1}{\phi})\end{aligned} \tag{D.6}$$

Similar considerations lead to a simplified price setting optimality condition in the non-traded sector:

$$\begin{aligned}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)\Big(\frac{\pi_{N,t}}{\pi_N}\Big) = \beta\Big[\Big(\frac{\pi_{N,t+1}}{\pi_N} - 1\Big)\Big(\frac{\pi_{N,t+1}}{\pi_N}\Big)\frac{\Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N} - 1\Big)^2\Big]}{\Big[1 - \frac{\psi_N}{2}\Big(\frac{\pi_{N,t+1}}{\pi_N} - 1\Big)^2\Big]}\Big] + \\ + \frac{\varphi}{\psi_N}\Big(mc_{N,t} - \frac{\varphi-1}{\varphi}\Big)\end{aligned} \tag{D.7}$$

Observe that while the dynamics of inflation in the traded sector are rich, as they depend on the relative expected growth rates and sectoral output, the NKPC in the nontraded sector closely resembles the relationship that would have been obtained in a closed economy model.

We proceed by expressing the risk sharing condition in terms of the restricted set of variables. From the UIP condition (B.11) and the consumption Euler Equation (B.4), it follows that:

$$\frac{1+g_{H,t+1}}{1+g^*}\Big(\frac{\pi_{H,t+1}}{\pi_{N,t+1}}\Big)\frac{\tau_{t+1}}{\tau_t}\frac{c_{N,t}}{c_{N,t+1}}\Omega(.)-1=0 \tag{D.8}$$

The remaining steps required for setting up the Ramsey problem consist of simple transformations made with respect to the real exchange rate and the dynamic current account equations. As we show below, real exchange rate fluctuations are a by-product of variations in the terms of trade and the relative price of nontraded goods.

$$q_t=\tau_t^{\theta}\rho_t^{\upsilon-1}=\tau_t^{\theta}\Big(\rho_{nh,t}\tau_t^{\theta-1}\Big)^{\upsilon-1}=\frac{\tau_t^{1-\upsilon(1-\theta)}}{\rho_{nh,t}^{1-\upsilon}}$$

With the alternative representation of q_t in mind, the dynamic current account equation becomes:

$$\begin{aligned}b_t&=\frac{(1+i_t^*)\Omega(.)}{(1+g^*)\pi_t^*}\frac{q_t}{q_{t-1}}b_{t-1}+(1+i_t^*)\Omega(.)tb_t=\\&=\frac{\Omega(.)}{\beta}\Big(\frac{\tau_t}{\tau_{t-1}}\Big)^{1-\upsilon+\theta\upsilon}\Big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\Big)^{1-\upsilon}b_{t-1}+(1+i_t^*)\Omega(.)\Big[\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}y_t-c_t\Big]\end{aligned} \tag{D.9}$$

where $y_t=\Big[1-\frac{\psi_H}{2}\Big(\frac{\pi_{H,t}}{\pi_H}-1\Big)^2\Big]y_{H,t}+\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N}-1\Big)^2\Big]\rho_{nh,t}\,y_{N,t}$

We are now ready to define the minimal form of the competitive allocation:

Proposition 1. *The allocation* $\{c_t,\pi_{H,t},\pi_{N,t},l_{H,t},l_{N,t},b_t,\tau_t,\rho_{nh,t},mc_{H,t},mc_{N,t}\}$ *defined by equations (D.1)-(D.9) and the transversality condition :*

$$\lim_{t\to\infty}\beta^t\frac{\lambda_{t+1}}{\pi_{t+1}}b_t=0$$

for all dates and under all contingencies, given the initial states τ_{-1}, $\rho_{nh,-1}$ *and* b_{-1}, *satisfies the restricted set of equilibrium conditions if and only if it satisfies the allocation defined in Appendix D.*

Proof. As the allocations in (D.1)-(D.9) have been derived based on the equilibrium conditions in Appendix B, it is clear that the they will also satisfy the original equilibrium. Thus, we only need to show how the plans for $\{c_{H,t},c_{N,t},\lambda_t,y_{H,t},y_{N,t},y_t,\rho_t,q_t,i_t,tb_t,l_t,w_t^d\}$ can be recovered once the restricted allocation is known. Given the optimal plan for τ_t and $\rho_{nh,t}$, ρ_t is obtained from (B.8). This allows to determine the real exchange rate in (B.10) and the sector demands in (B.1) and (B.2). The interest rate is obtained from the Euler equation (B.4). Knowing the paths of the labour supply allows us to determine the sector and aggregate outputs. Finally, the real wage is recovered from equation (B.5), following the previously obtained solution for aggregate labour and consumption. □

E The First Order Conditions of the Ramsey Problem

As illustrated in section 1.3.2, the allocation decision faced by the Ramsey planner requires him to solve the constrained optimisation problem detailed below.

$$
\begin{aligned}
&\max_{mc_{H,t},mc_{N,t},l_{H,t},l_{N,t},c_t,\pi_{H,t},\pi_{N,t},\rho_{nh,t},\tau_t,b_t} \sum_{t=0}^{\infty} \beta^t \Bigg\{ ln(c_t) - \frac{(l_{H,t}+l_{N,t})^{1+\eta}}{1+\eta} \\
&+\mu_{1,t}\Bigg[\frac{(\frac{\pi_{H,t}}{\pi_H}-1)(\frac{\pi_{H,t}}{\pi_H})l_{H,t}}{\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}} - \beta\frac{1+g_{H,t+1}}{1+g^*}(\frac{\pi_{H,t+1}}{\pi_{N,t+1}})\frac{(\frac{\pi_{H,t+1}}{\pi_H}-1)(\frac{\pi_{H,t+1}}{\pi_H})l_{H,t+1}}{\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t+1}}{\pi_N}-1)^2\Big]l_{N,t+1}} \\
&\quad - \frac{\phi\ l_{H,t}}{\psi_H\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]l_{N,t}}(mc_{H,t}-\frac{\phi-1}{\phi})\Bigg] \\
&+\mu_{2,t}\Bigg[\frac{(\frac{\pi_{N,t}}{\pi_N}-1)(\frac{\pi_{N,t}}{\pi_N})}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]} - \beta\frac{(\frac{\pi_{N,t+1}}{\pi_N}-1)(\frac{\pi_{N,t+1}}{\pi_N})}{\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t+1}}{\pi_N}-1)^2\big]} - \frac{\varphi}{\psi_N\big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\big]}(mc_{N,t}-\frac{\varphi-1}{\varphi})\Bigg] \\
&+\mu_{3,t}\Bigg[\frac{1}{\Omega(.)}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}} - \Big[\frac{1+g_{H,t+1}}{1+g^*}(\frac{\pi_{H,t+1}}{\pi_{N,t+1}})\frac{\tau_{t+1}}{\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t+1}}{\pi_N}-1)^2\Big]l_{N,t+1}}\Big]\Bigg] \\
&+\mu_{4,t}\Big[mc_{N,t} - \frac{(l_{H,t}+l_{N,t})^{\eta}}{(1-\upsilon)}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}\Big] \\
&+\mu_{5,t}\Big[mc_{H,t}-\rho_{nh,t}mc_{N,t}\Big] \\
&+\mu_{6,t}\Big[\rho_{nh,t} - \Big(\frac{1+g^*}{1+g_{H,t}}\Big)\frac{\pi_{N,t}}{\pi_{H,t}}\rho_{nh,t-1}\Big] \\
&+\mu_{7,t}\Bigg[\tau_t - \frac{\Big[1-\frac{\psi_H}{2}(\frac{\pi_{H,t}}{\pi_H}-1)^2\Big]l_{H,t} - \frac{\theta\upsilon}{1-\upsilon}\rho_{nh,t}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}}{(1-\theta^*)y_t^*}\Bigg] \\
&+\mu_{8,t}\Bigg[c_t - \frac{1}{1-\upsilon}\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)}\Bigg] \\
&+\mu_{9,t}\Bigg[b_t - \frac{\Omega(.)}{\beta}(\frac{\tau_t}{\tau_{t-1}})^{1-\upsilon+\theta\upsilon}(\frac{\rho_{nh,t-1}}{\rho_{nh,t}})^{1-\upsilon}b_{t-1} - (1+i_t^*)\Omega(.)\Big[\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}y_t - c_t\Big]\Bigg]\Bigg\}
\end{aligned}
$$

The conditions necessary for the existence of an optimal plan are equations (D.1)-(D.9) and:

$$c_t: \qquad \frac{1}{c_t} + \mu_{8,t} + (1+i^*)\Omega(.)\mu_{9,t} = 0 \tag{E.1}$$

$$l_{H,t}: \qquad -(l_{H,t}+l_{N,t})^{\eta} + \frac{(\frac{\pi_{H,t}}{\pi_H}-1)(\frac{\pi_{H,t}}{\pi_H})}{[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2]l_{N,t}}[\mu_{1,t} - (\frac{1+g_{H,t}}{1+g^*})(\frac{\pi_{H,t}}{\pi_{N,t}})\mu_{1,t-1}]$$
$$-\mu_{1,t}\frac{\phi}{\psi_H[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2]l_{N,t}}(mc_{H,t}-\frac{\phi-1}{\phi}) - \mu_{4,t}\frac{\eta(l_{H,t}+l_{N,t})^{\eta-1}}{(1-\upsilon)}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}$$
$$-\mu_{7,t}\frac{\Big[1-\frac{\psi_H}{2}(\frac{\pi_{H,t}}{\pi_H}-1)^2\Big]}{(1-\theta^*)y^*} - \mu_{9,t}(1+i^*)\Omega(.)\rho_{nh,t}^{\upsilon-1}\tau^{\upsilon(\theta-1)}\Big[1-\frac{\psi_H}{2}(\frac{\pi_{H,t}}{\pi_H}-1)^2\Big]$$
$$-\mu_{3,t}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_N,t}{\pi_N}-1\Big)^2\Big]l_{N,t}}\frac{\frac{\partial\Omega(.)}{\partial l_{H,t}}}{\Omega(.)^2}-$$
$$\mu_{9,t}\Big[\frac{1}{\beta}(\frac{\tau_t}{\tau_{t-1}})^{1-\upsilon+\theta\upsilon}(\frac{\rho_{nh,t-1}}{\rho_{nh,t}})^{1-\upsilon}b_{t-1} + (1+i^*)[\rho_{nh,t}^{\upsilon-1}\tau^{\upsilon(\theta-1)}y_t - c_t]\Big]\frac{\partial\Omega(.)}{\partial l_{H,t}} = 0 \tag{E.2}$$

$$l_{N,t}: \qquad -(l_{H,t}+l_{N,t})^{\eta} - \frac{(\frac{\pi_{H,t}}{\pi_H}-1)(\frac{\pi_{H,t}}{\pi_H})l_{H,t}}{[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2]l_{N,t}}\frac{1}{l_{N,t}}[\mu_{1,t} - (\frac{1+g_{H,t}}{1+g^*})(\frac{\pi_{H,t}}{\pi_{N,t}})\mu_{1,t-1}]$$
$$+\mu_{1,t}\frac{\phi l_{H,t}}{\psi_H\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}}\frac{1}{l_{N,t}}\Big(mc_{H,t}-\frac{\phi-1}{\phi}\Big)$$
$$-\left[\frac{1}{\Omega(.)}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t}}\frac{1}{l_{N,t}}\right][\mu_{3,t} - \frac{\Omega(.)}{\beta}(\frac{1+g_{H,t}}{1+g^*})(\frac{\pi_{H,t}}{\pi_{N,t}})\mu_{3,t-1}]$$
$$-\mu_{4,t}\left[\frac{\eta\big(l_{H,t}+l_{N,t}\big)^{\eta-1}}{(1-\upsilon)}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]l_{N,t} + \frac{(l_{H,t}+l_{N,t})^{\eta}}{1-\upsilon}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]\right]$$
$$+\mu_{7,t}\frac{\frac{\theta\upsilon}{1-\upsilon}\rho_{nh,t}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]}{(1-\theta^*)y^*} - \mu_{8,t}\frac{1}{1-\upsilon}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big]\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)}$$
$$-\mu_{9,t}(1+i^*)\Omega(.)\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)}\Big[1-\frac{\psi_N}{2}(\frac{\pi_{N,t}}{\pi_N}-1)^2\Big] - \mu_{3,t}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_N,t}{\pi_N}-1\Big)^2\Big]l_{N,t}}\frac{\frac{\partial\Omega(.)}{\partial l_{N,t}}}{\Omega(.)^2}$$
$$-\mu_{9,t}\Big[\frac{1}{\beta}(\frac{\tau_t}{\tau_{t-1}})^{1-\upsilon+\theta\upsilon}(\frac{\rho_{nh,t-1}}{\rho_{nh,t}})^{1-\upsilon}b_{t-1} + (1+i^*)[\rho_{nh,t}^{\upsilon-1}\tau^{\upsilon(\theta-1)}y_t - c_t]\Big]\frac{\partial\Omega(.)}{\partial l_{N,t}} = 0 \tag{E.3}$$

$$\pi_{H,t}: \qquad \frac{\frac{l_{H,t}}{\pi_H}\big(\frac{2\pi_{H,t}}{\pi_H}-1\big)}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}\Big[\mu_{1,t}-\big(\frac{1+g_{H,t}}{1+g^*}\big)\big(\frac{\pi_{H,t}}{\pi_{N,t}}\big)\mu_{1,t-1}\Big]$$

$$-\frac{1+g_{H,t}}{1+g^*}\frac{1}{\pi_{N,t}}\frac{\big(\frac{\pi_{H,t}}{\pi_H}-1\big)\big(\frac{\pi_{H,t}}{\pi_H}\big)l_{H,t}}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}\mu_{1,t-1}-\frac{1}{\beta}\big(\frac{1+g_{H,t}}{1+g^*}\big)\frac{1}{\pi_{N,t}}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}\mu_{3,t-1}$$

$$+\mu_{6,t}\frac{\rho_{nh,t}}{\pi_{H,t}}+\mu_{7,t}\frac{\frac{\psi_H}{\pi_H}\big(\frac{\pi_{H,t}}{\pi_H}-1\big)l_{H,t}}{(1-\theta^*)y^*}+\mu_{9,t}(1+i^*)\Omega(.)\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}\frac{\psi_H}{\pi_H}\big(\frac{\pi_{H,t}}{\pi_H}-1\big)l_{H,t}$$

$$-\mu_{3,t}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N}-1\Big)^2\Big]l_{N,t}}\frac{\frac{\partial\Omega(.)}{\partial\pi_{H,t}}}{\Omega(.)^2}$$

$$-\mu_{9,t}\Big[\frac{1}{\beta}\big(\frac{\tau_t}{\tau_{t-1}}\big)^{1-\upsilon+\theta\upsilon}\big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\big)^{1-\upsilon}b_{t-1}+(1+i^*)\big[\rho_{nh,t}^{\upsilon-1}\tau^{\upsilon(\theta-1)}y_t-c_t\big]\Big]\frac{\partial\Omega(.)}{\partial\pi_{H,t}}=0 \tag{E.4}$$

$$\pi_{N,t}: \qquad \frac{\big(\frac{\pi_{H,t}}{\pi_H}-1\big)\big(\frac{\pi_{H,t}}{\pi_H}\big)l_{H,t}}{l_{N,t}\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]}\frac{\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]}\big(\mu_{1,t}-\big(\frac{1+g_{H,t}}{1+g^*}\big)\big(\frac{\pi_{H,t}}{\pi_{N,t}}\big)\mu_{1,t-1}\big)$$

$$+\big(\frac{1+g_{H,t}}{1+g^*}\big)\big(\frac{\pi_{H,t}}{\pi_{N,t}}\big)\big(\frac{1}{\pi_{N,t}}\big)\frac{\big(\frac{\pi_{H,t}}{\pi_H}-1\big)\big(\frac{\pi_{H,t}}{\pi_H}\big)l_{H,t}}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}\mu_{1,t-1}-\mu_{1,t}\frac{\phi\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)l_{H,t}}{\psi_H\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]^2l_{N,t}}$$

$$(mc_{H,t}-\frac{\phi-1}{\phi})+\Bigg[\frac{\big(\frac{\pi_{N,t}}{\pi_N}-1\big)\big(\frac{\pi_{N,t}}{\pi_N}\big)}{1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2}\frac{\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)}{1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2}+\frac{\frac{1}{\pi_N}\big(\frac{2\pi_{N,t}}{\pi_N}-1\big)}{1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2}\Bigg](\mu_{2,t}-\mu_{2,t-1})$$

$$-\mu_{2,t}\frac{\frac{\varphi}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]^2}(mc_{N,t}-\frac{\varphi-1}{\varphi})$$

$$+\Bigg[\frac{1}{\Omega(.)}\frac{\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)\tau_t}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]^2l_{N,t}}\Bigg]\big[\mu_{3,t}-\frac{\Omega(.)}{\beta}\big(\frac{1+g_{H,t}}{1+g^*}\big)\big(\frac{\pi_{H,t}}{\pi_{N,t}}\big)\mu_{3,t-1}\big]$$

$$+\frac{1}{\beta}\big(\frac{1+g_{H,t}}{1+g^*}\big)\big(\frac{\pi_{H,t}}{\pi_{N,t}}\big)\frac{1}{\pi_{N,t}}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}\mu_{3,t-1}$$

$$+\mu_{4,t}\frac{(l_{H,t}+l_{N,t})^\eta}{(1-\upsilon)}\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)l_{N,t}-\mu_{6,t}\frac{\rho_{nh,t}}{\pi_{N,t}}-\mu_{7,t}\frac{\frac{\theta\upsilon}{1-\upsilon}\rho_{nh,t}\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)l_{N,t}}{(1-\theta^*)y^*}$$

$$+\frac{\mu_{8,t}}{1-\upsilon}\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)l_{N,t}\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)}+\mu_{9,t}(1+i^*)\Omega(.)\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)}\frac{\psi_N}{\pi_N}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)l_{N,t}$$

$$-\mu_{3,t}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N}-1\Big)^2\Big]l_{N,t}}\frac{\frac{\partial\Omega(.)}{\partial\pi_{N,t}}}{\Omega(.)^2}$$

$$-\mu_{9,t}\Big[\frac{1}{\beta}\big(\frac{\tau_t}{\tau_{t-1}}\big)^{1-\upsilon+\theta\upsilon}\big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\big)^{1-\upsilon}b_{t-1}+(1+i^*)\big[\rho_{nh,t}^{\upsilon-1}\tau^{\upsilon(\theta-1)}y_t-c_t\big]\Big]\frac{\partial\Omega(.)}{\partial\pi_{N,t}}=0 \tag{E.5}$$

$$mc_{H,t}: \qquad -\mu_{1,t}\frac{\phi l_{H,t}}{\psi_H\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}+\mu_{5,t}=0 \tag{E.6}$$

$$mc_{N,t}: \qquad -\mu_{2,t}\frac{\varphi}{\psi_N\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]}+\mu_{4,t}-\mu_{5,t}\rho_{nh,t}=0 \tag{E.7}$$

$$\begin{aligned}
\tau_t: \qquad & \frac{1}{\Omega_t(.)\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}\big[\mu_{3,t}-\frac{\Omega_t(.)}{\beta}\big(\frac{1+g_{H,t}}{1+g^*}\big)\big(\frac{\pi_{H,t}}{\pi_{N,t}}\big)\mu_{3,t-1}\big]+\mu_{7,t}\\
&+\mu_{8,t}\frac{\upsilon(1-\theta)}{1-\upsilon}\rho_{nh,t}^{\upsilon}\tau_t^{\upsilon(\theta-1)-1}\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}\\
&-\mu_{9,t}\Big[\frac{\Omega_t(.)}{\beta}(1-\upsilon+\theta\upsilon)\big(\frac{\tau_t}{\tau_{t-1}}\big)^{1-\upsilon+\theta\upsilon}\frac{1}{\tau_t}\big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\big)^{1-\upsilon}b_{t-1}\Big]+\mu_{9,t}\upsilon(1-\theta)(1+i^*)\Omega_t(.)\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}\frac{1}{\tau_t}y_t\\
&+\mu_{9,t+1}\Big[(1-\upsilon+\theta\upsilon)\Omega_{t+1}()\big(\frac{\tau_{t+1}}{\tau_t}\big)^{1-\upsilon+\theta\upsilon}\frac{1}{\tau_t}\big(\frac{\rho_{nh,t}}{\rho_{nh,t+1}}\big)^{1-\upsilon}b_t\Big]-\mu_{3,t}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N}-1\Big)^2\Big]l_{N,t}}\frac{\frac{\partial\Omega(.)}{\partial\tau_t}}{\Omega(.)^2}\\
&-\mu_{9,t}\Big[\frac{1}{\beta}\big(\frac{\tau_t}{\tau_{t-1}}\big)^{1-\upsilon+\theta\upsilon}\big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\big)^{1-\upsilon}b_{t-1}+(1+i^*)\big[\rho_{nh,t}^{\upsilon-1}\tau^{\upsilon(\theta-1)}y_t-c_t\big]\Big]\frac{\partial\Omega(.)}{\partial\tau_t}=0
\end{aligned} \tag{E.8}$$

$$\begin{aligned}
\rho_{nh,t}: \qquad & -\mu_{5,t}mc_{N,t}+\mu_{6,t}-\mu_{6,t+1}\beta\big(\frac{\rho_{nh,t+1}}{\rho_{nh,t}}\big)+\mu_{7,t}\frac{\frac{\theta\upsilon}{1-\upsilon}\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}{(1-\theta^*)y^*}\\
&-\mu_{8,t}\frac{\upsilon}{1-\upsilon}\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}l_{N,t}+\mu_{9,t}(1-\upsilon)\frac{\Omega_t(.)}{\beta}\big(\frac{\tau_t}{\tau_{t-1}}\big)^{1-\upsilon+\theta\upsilon}\big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\big)^{1-\upsilon}\frac{1}{\rho_{nh,t}}b_{t-1}\\
&-\mu_{9,t}\Big[\upsilon(1+i^*)\Omega_t(.)\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}-\\
&\qquad -(1-\upsilon)(1+i^*)\Omega_t(.)\rho_{nh,t}^{\upsilon-2}\tau_t^{\upsilon(\theta-1)}\Big[1-\frac{\psi_H}{2}\big(\frac{\pi_{H,t}}{\pi_H}-1\big)^2\Big]l_{H,t}\Big]\\
&-\mu_{9,t+1}(1-\upsilon)\Omega_{t+1}(.)\big(\frac{\tau_{t+1}}{\tau_t}\big)^{1-\upsilon+\theta\upsilon}\Big(\frac{\rho_{nh,t}}{\rho_{nh,t+1}}\Big)^{1-\upsilon}\frac{1}{\rho_{nh,t}}b_t-\mu_{3,t}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\Big(\frac{\pi_{N,t}}{\pi_N}-1\Big)^2\Big]l_{N,t}}\frac{\frac{\partial\Omega(.)}{\partial\rho_{nh,t}}}{\Omega(.)^2}\\
&-\mu_{9,t}\Big[\frac{1}{\beta}\big(\frac{\tau_t}{\tau_{t-1}}\big)^{1-\upsilon+\theta\upsilon}\big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\big)^{1-\upsilon}b_{t-1}+(1+i^*)\big[\rho_{nh,t}^{\upsilon-1}\tau^{\upsilon(\theta-1)}y_t-c_t\big]\Big]\frac{\partial\Omega(.)}{\partial\rho_{nh,t}}=0
\end{aligned} \tag{E.9}$$

$$\begin{aligned}
b_t: \qquad & -\mu_{3,t}\frac{\frac{\partial\Omega_t(.)}{\partial b_t}}{\Omega_t^2(.)}\frac{\tau_t}{\Big[1-\frac{\psi_N}{2}\big(\frac{\pi_{N,t}}{\pi_N}-1\big)^2\Big]l_{N,t}}+\mu_{9,t}-\mu_{9,t+1}\Omega_{t+1}(.)\big(\frac{\tau_{t+1}}{\tau_t}\big)^{1-\upsilon+\theta\upsilon}\big(\frac{\rho_{nh,t}}{\rho_{nh,t+1}}\big)^{1-\upsilon}\\
&-\mu_{9,t}\left[\frac{\frac{\partial\Omega_t(.)}{\partial b_t}}{\beta}\big(\frac{\tau_t}{\tau_{t-1}}\big)^{1-\upsilon+\theta\upsilon}\big(\frac{\rho_{nh,t-1}}{\rho_{nh,t}}\big)^{1-\upsilon}b_{t-1}+(1+i^*)\frac{\partial\Omega(.)}{\partial b_t}\Big[\rho_{nh,t}^{\upsilon-1}\tau_t^{\upsilon(\theta-1)}y_t-c_t\Big]\right]=0
\end{aligned} \tag{E.10}$$

F The Nonstochastic Steady State

Assume that $x_{t-1} = x_t = x_{t+1} = x$ for all endogenous variables. Then, the system of equilibrium conditions depicted by equations (D.1)-(D.9) can be used to solve for the steady state of the Ramsey economy.

For an exogenous value of b and a corresponding function $\Omega(.) = 1$, equation (D.9) reads:

$$b = \frac{b}{\beta} + \frac{(1+g^*)\pi^*}{\beta} tb \tag{F.1}$$

For a given b, the trade balance is:

$$tb = -\frac{1-\beta}{(1+g^*)\pi^*} b \tag{F.2}$$

The real marginal costs are determined in steady state from the dynamic price adjustment equations (B.16) and (B.17). The resulting expressions are standard: the real marginal costs are equal to the inverse of the steady state markup characterising each sector.

$$mc_H = \frac{\phi - 1}{\phi} \tag{F.3}$$

$$mc_N = \frac{\varphi - 1}{\varphi} \tag{F.4}$$

It follows from (D.2) that :

$$\rho_{nh} = \frac{mc_H}{mc_N} \tag{F.5}$$

The last result helps us to characterise the steady state relative demands in the two sectors:

$$c_H = \frac{\theta \upsilon}{1-\upsilon} \rho_{nh} c_N \tag{F.6}$$

Given that the quadratic adjustment cost terms are 0, the market clearing condition in the nontraded goods sector becomes :

$$y_N = c_N \tag{F.7}$$

Using the last two equations, the trade balance can be written as:

$$tb = \frac{\rho^{\upsilon}}{\rho_{nh}} y - c = \frac{\rho^{\upsilon}}{\rho_{nh}} (y_H + \rho_{nh} y_N) - \frac{\rho^{\upsilon}}{1-\upsilon} y_N = \frac{\rho^{\upsilon}}{\rho_{nh}} (y_H - \frac{\upsilon}{1-\upsilon} \rho_{nh} y_N) \tag{F.8}$$

Conditional on the trade balance being in equilibrium ($tb = 0$), equation (F.8) fully characterises the production possibilities frontier of the economy. Note that in the simplied case of financial autarky, the production possibilities frontier of Y_N and Y_H is linear. Its slope depends only on the relative size of the tradable and nontradable sectors and on the relative price of the two goods. The result depends on the perfect substitutitability of the labour input across sectors and on the linear CRTS production functions. Thus, an exogenous change in the trade balance caused, for example, by foreign factors, would induce a substantial change in the relative labour supply across the two sectors.[68] In the general case where $tb \neq 0$, the condition will only impose a lower boundary restriction on the relative supplies of the two goods. This is because the relative price term $\frac{\rho^{\upsilon}}{\rho_{nh}}$ is always positive.

The steady state terms of trade are obtained from (D.4):

$$\tau = \frac{y_H - \frac{\theta\upsilon}{1-\upsilon}\rho_{nh}y_N}{(1-\theta^*)y^*} \tag{F.9}$$

Given the steady state values of the terms of trade and the internal price ratio, ρ is simply:

$$\rho = \rho_{nh}\tau^{\theta-1} \tag{F.10}$$

This completes the derivation of the relative prices, which are all written as functions of the real variables in the model.

The only remaining task is to determine the steady state allocation of hours across the two sectors. From equation (D.1), l_N is related to l by:

$$\frac{(1-\upsilon)mc_{N,t}}{l_N} = (l_H + l_N)^{\eta} \tag{F.11}$$

Given the solution obtained earlier for ρ_{nh} and tb, the system of equations in (F.8)-(F.11) allows us to compute the steady state values of τ, ρ, l_N and l_H as a function of the structural parameters of the model.

Note that when the trade balance is different from zero, an analytical solution is not generally available, as we will show below. The need to resort to numerical methods arises from the presence of the power terms υ and η in (F.8) and (F.11), which represent the share of the traded goods sector and the inverse of the Frisch elasticity of labour supply. As an initial value b_{-1} different from 0 would considerably complicate the characterisation of the Ramsey steady state, without bringing other insights to the analysis, we restrict the steady state trade balance to be in equilibrium.

[68]This effect might be at odds with the data - see Mendoza, Uribe(2000) for a related discussion

Imposing $tb = 0$ in the Initial Steady State

From equation (F.8), the levels of output in each sector are related by :

$$y_H = \frac{\upsilon}{1-\upsilon}\rho_{nh} y_N \tag{F.12}$$

Using the production functions in (B.12) and (B.13) and the expression for ρ_{nh} in (F.5) :

$$l_H = \frac{\upsilon}{1-\upsilon}\frac{mc_H}{mc_N} l_N$$

Then, the aggregate labour supply is given by:

$$l = l_H + l_N = \Big(\frac{\upsilon}{1-\upsilon}\frac{mc_H}{mc_N} + 1\Big) l_N = \Big[\frac{\upsilon mc_H + (1-\upsilon)mc_N}{(1-\upsilon)mc_N}\Big]\frac{(1-\upsilon)mc_N}{l^{\eta}}$$

Rearranging for l :

$$l = [\upsilon mc_H + (1-\upsilon)mc_N]^{\frac{1}{1+\eta}} \tag{F.13}$$

The number of hours worked in each sector are then straightforward to obtain from (F.11):

$$l_N = (1-\upsilon)mc_N[\upsilon mc_H + (1-\upsilon)mc_N]^{-\frac{\eta}{1+\eta}} \tag{F.14}$$

$$l_H = \upsilon mc_H[\upsilon mc_H + (1-\upsilon)mc_N]^{-\frac{\eta}{1+\eta}} \tag{F.15}$$

Finally, given the relationship between the sectoral output variables in (F.12), the steady state condition for the terms of trade becomes:

$$\tau = \frac{y_H - \frac{\theta\upsilon}{1-\upsilon}\rho_{nh} y_N}{(1-\theta^*)y^*} = \frac{y_H - \theta y_H}{(1-\theta^*)y^*} = \frac{(1-\theta)y_H}{(1-\theta^*)y^*} \tag{F.16}$$

G Analytical Proof of the Claim Regarding the Absence of Long-run Structural Change

This appendix provides a simple analytical framework that justifies the claims made in the main text regarding structural change. To this end, we propose a simple two-sector closed economy model, where we relax the Cobb-Douglas functional form previously used to define the aggregate consumption good. Within this context, we also show the role played by the perfect labour mobility assumption in influencing the long-run independence of hours from relative productivity shocks. To preserve the comparability with the benchmark model, we maintain the monopolistically competitive market structures of the two sectors. Without altering the long-run implications, the analysis is focused on the flexible price allocation associated with the decentralised equilibrium.

Consumers

We consider a more general class of additive-separable preferences defined over the consumption and labour goods. Consumers make decisions in each time period in order to maximise the following objective function:

$$U_t = \sum_{t=0}^{\infty} \beta^t [u(C_t) - \frac{L_t^{1+\eta}}{1+\eta}] \tag{G.1}$$

The only restrictions we impose on $u(C_t)$ is that it is increasing and concave : $u' > 0$, $u'' < 0$. While the benchmark simulations were conducted contingent on perfect labour mobility, we consider a more general class of economy-wide labour aggregates:

$$L_t = \frac{(L_{H,t}^{1+\gamma} + L_{N,t}^{1+\gamma})}{1+\gamma} \tag{G.2}$$

where γ is a parameter that governs the degree of labour mobility across the economy. The case of perfect substitution across the two types is encompassed as a special case ($\gamma = 0$).

As it can be noticed from the above equation, consumption choices are defined over two goods, indexed by H and N. Aggregate consumption is related to the sector specific measures according to a CES aggregator:

$$C_t = \left[\upsilon^{\frac{1}{\zeta}} C_{H,t}^{\frac{\zeta-1}{\zeta}} + (1-\upsilon)^{\frac{1}{\zeta}} C_{N,t}^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}} \tag{G.3}$$

where $\zeta > 0$ is a parameter governing the elasticity of substitution between $C_{H,t}$ and $C_{N,t}$. A unitary value of ζ would imply that C_t has a Cobb Douglas functional form, similar to the one used in the benchmark model.

Minimising the cost of purchasing the final good results in the following demand functions:

$$C_{H,t} = \upsilon(\frac{P_{H,t}}{P_t})^{-\zeta} C_t \tag{G.4}$$

$$C_{N,t} = (1-\upsilon)(\frac{P_{N,t}}{P_t})^{-\zeta} C_t \tag{G.5}$$

Moreover, the intratemporal optimisation problem has an associated CPI index P_t defined as:

$$P_t = \left[\upsilon P_{H,t}^{1-\zeta} + (1-\upsilon) P_{N,t}^{1-\zeta}\right]^{\frac{1}{1-\zeta}} \tag{G.6}$$

In maximising the lifetime utility function in (G.1), consumers are faced with the following budget constraint:

$$C_t + \frac{B_t}{P_t(1+i_t)} \leq \frac{B_{t-1}}{P_t} + \frac{W_{H,t}L_{H,t}}{P_t} + \frac{W_{N,t}L_{N,t}}{P_t} + \frac{\Pi_t}{P_t} \tag{G.7}$$

The optimal path of consumption, sector specific labour and domestic bond holdings is associated with the following first order conditions:

$$\Lambda_t = u'(C_t) \tag{G.8}$$

$$\Lambda_t = \beta(1+i_t)\frac{P_t}{P_{t+1}}\Lambda_{t+1} \tag{G.9}$$

$$L_t^{\eta} L_{H,t}^{\gamma} = \Lambda_t \frac{W_{H,t}}{P_t} \tag{G.10}$$

$$L_t^{\eta} L_{N,t}^{\gamma} = \Lambda_t \frac{W_{N,t}}{P_t} \tag{G.11}$$

By relaxing the assumption of perfect labour substitutability, the sector specific nominal wages are not equal any longer. However, a simple relation between the two can be derived if equations (G.10) and (G.11) are divided:

$$\frac{W_{H,t}}{W_{N,t}} = (\frac{L_{H,t}}{L_{N,t}})^{\gamma} \tag{G.12}$$

Producers

The supply side of the model is similar to one in the main text, defined by equations (1.16)-(1.21) and (1.27)-(1.30). As the analysis intends to derive the long-run implications for structural change, we maintain our focus on the flexible price allocation, characterised by the restrictions $\psi_H = \psi_N = 0$. If follows that :

$$Y_{H,t} = \Gamma_{H,t} L_{H,t} \tag{G.13}$$

$$Y_{N,t} = \Gamma_{N,t} L_{N,t} \tag{G.14}$$

The only asymmetry between the two sectors that is maintained throughout our exposition is that technological change in the H sector is higher.

$$\frac{\frac{d}{dt}\Gamma_{H,t}}{\Gamma_{H,t}} = 1 + g_{H,t} \tag{G.15}$$

$$\frac{\frac{d}{dt}\Gamma_{N,t}}{\Gamma_{N,t}} = 1 + g_{N,t} \tag{G.16}$$

with $g_{H,t} > g_{N,t}$.

When the flexible price restrictions are imposed on equations (1.27) and (1.29), the following conditions hold:

$$mc_{H,t} = \frac{\phi - 1}{\phi} \tag{G.17}$$

$$mc_{N,t} = \frac{\varphi - 1}{\varphi} \tag{G.18}$$

The real marginal costs are defined by:

$$mc_{H,t} = \frac{W_{H,t}}{P_{H,t}} \frac{1}{\Gamma_{H,t}} \tag{G.19}$$

$$mc_{N,t} = \frac{W_{N,t}}{P_{N,t}} \frac{1}{\Gamma_{N,t}} \tag{G.20}$$

Market Clearing Conditions

The model is closed with the market clearing conditions:

$$C_{H,t} = Y_{H,t} \tag{G.21}$$

$$C_{N,t} = Y_{N,t} \tag{G.22}$$

$$B_t = 0 \tag{G.23}$$

We can now derive the model's implications for the relative labour supply dynamics. To do so, we first divide equations (G.19) and (G.20). This enables us to express the relative price of the two goods as:

$$R_{NH,t} = \frac{P_{N,t}}{P_{H,t}} = \frac{mc_{H,t}}{mc_{N,t}}\frac{W_{N,t}}{W_{H,t}}\frac{\Gamma_{H,t}}{\Gamma_{N,t}} = \frac{mc_{H,t}}{mc_{N,t}}(\frac{L_{N,t}}{L_{H,t}})^{\gamma}\frac{\Gamma_{H,t}}{\Gamma_{N,t}} \tag{G.24}$$

Given the fixed values of the real marginal costs implied by equations (G.17) and (G.18), we can take logs and differentiate with respect to time. This enables us to express to growth rate of relative prices as:

$$\frac{\frac{d}{dt}R_{NH,t}}{R_{NH,t}} = \gamma\left(\frac{\frac{d}{dt}L_{N,t}}{L_{N,t}} - \frac{\frac{d}{dt}L_{H,t}}{L_{H,t}}\right) + (g_{H,t} - g_{N,t}) \tag{G.25}$$

Another expression for $R_{NH,t}$ can be obtained from equations (G.4) and (G.5):

$$\frac{Y_{H,t}}{Y_{N,t}} = \frac{\upsilon}{1-\upsilon}R_{NH,t}{}^{\zeta} \tag{G.26}$$

Using the production functions in (G.13) and (G.14), this translates to:

$$\frac{\Gamma_{H,t}L_{H,t}}{\Gamma_{N,t}L_{N,t}} = \frac{\upsilon}{1-\upsilon}R_{NH,t}{}^{\zeta} \tag{G.27}$$

Or, in growth rates:

$$(g_{H,t} - g_{N,t}) + \left(\frac{\frac{d}{dt}L_{H,t}}{L_{H,t}} - \frac{\frac{d}{dt}L_{N,t}}{L_{N,t}}\right) = \zeta\frac{\frac{d}{dt}R_{NH,t}}{R_{NH,t}} \tag{G.28}$$

Substituting for $\frac{\frac{d}{dt}R_{NH,t}}{R_{NH,t}}$ from (G.25) into (G.28), the dynamics of relative labour supply can be derived as:

$$(g_{H,t} - g_{N,t}) + \left(\frac{\frac{d}{dt}L_{H,t}}{L_{H,t}} - \frac{\frac{d}{dt}L_{N,t}}{L_{N,t}} \right) = \gamma\zeta \left(\frac{\frac{d}{dt}L_{N,t}}{L_{N,t}} - \frac{\frac{d}{dt}L_{H,t}}{L_{H,t}} \right) + \zeta(g_{H,t} - g_{N,t}) \tag{G.29}$$

From where :

$$\frac{\frac{d}{dt}L_{N,t}}{L_{N,t}} - \frac{\frac{d}{dt}L_{H,t}}{L_{H,t}} = \frac{1-\zeta}{1+\zeta\gamma}(g_{H,t} - g_{N,t}) \tag{G.30}$$

This proves the claim in the main text.

In the context of the above closed economy model, relative hours grow in inverse proportion to the relative productivity growth rates, with the factor of proportionality being influenced by the elasticity of substitution between the two goods, ζ, and the degree of labour mobility in the economy, γ. Moreover, as in Ngai and Pissarides (2007), a unitary elasticity of substitution is consistent with an absence of long run structural change.

H The Steady State System

Our objective in this section is to express the stationary values of all endogenous variables as a function of the structural parameters of the economy. This will be useful in constructing the loglinear approximation we discuss in Appendix I.

We characterise the steady-state system by choosing an exogenous equilibrium net foreign assets position given by $b^F = \bar{b} = 0$. The non-stochastic steady-state around which we approximate the model's dynamics also assumes that full indexation takes place ($\chi_p = \chi_w = 1$) and that all relative prices are equal to 1:

$$T = 1 \tag{H.1}$$

The above restriction is sufficient to insure that all measures of inflation in the model are equal (see equation (3.25)):

$$\pi = \pi^h = \pi^f \tag{H.2}$$

The steady-state expressions of q and r^k are determined from equations (3.20) and (3.21):

$$q = 1, \qquad r^k = \frac{1-\beta}{\beta} + \delta \tag{H.3}$$

From (3.44), (3.45), we obtain the solution for the real wage:

$$w = \Big[\frac{\rho - 1}{\rho}\frac{(1-\alpha)^{1-\alpha}\alpha^{\alpha}}{r^k}\Big]^{\frac{1}{1-\alpha}} \tag{H.4}$$

Using the input demand functions (3.31), (3.32) and the balanced trade equation (3.66) gives:

$$Y^{h,d} = \upsilon Y + (1-\upsilon)Y = Y \tag{H.5}$$

The fixed cost parameter (ϕ) is chosen such that steady-state real profits in the intermediate sector are zero:

$$\Pi^h = Y^{h,d} - r^k K - wL = K^{\alpha}L^{1-\alpha} - \phi - r^k K - wL = 0 \tag{H.6}$$

It follows that :

$$\phi = K^{\alpha}L^{1-\alpha} - r^k K - wL \tag{H.7}$$

and, using the relationship for the capital-labour ratio in (3.40):

$$Y^{h,d} = r^K K + wL = \frac{r^k K}{\alpha} = \frac{wL}{1-\alpha} \tag{H.8}$$

Next, (H.8) is combined with the market clearing condition for output (3.64), the relationship we derived in (H.5) and the steady state investment condition from (3.6) ($I = \delta K$) to give:

$$Y^{h,d} = C + \delta K \tag{H.9}$$

From where:

$$C = [1 - \frac{\delta\alpha}{r^k}]Y^{h,d} \tag{H.10}$$

We can now substitute the above results in the relationship between the real wage and the marginal rate of substitution between consumption and hours (3.13):

$$w = \frac{\varphi}{\varphi - 1}\frac{L^\eta}{\lambda} \tag{H.11}$$

$$w = \frac{\varphi}{\varphi - 1}L^\eta(1-\gamma)^\sigma C^\sigma = \frac{\varphi}{\varphi - 1}(\frac{1-\alpha}{w})^\eta(1-\gamma)^\sigma\Big[1 - \frac{\delta\alpha}{r^k}\Big]^\sigma(Y^{h,d})^{\eta+\sigma} \tag{H.12}$$

This allows us to derive the steady-state value of domestic intermediate output:

$$Y^{h,d} = \left[\frac{(\varphi-1)w^{1+\eta}}{\varphi(1-\alpha)^\eta(1-\gamma)^\sigma\Big[1-\frac{\delta\alpha}{r^k}\Big]^\sigma}\right]^{\frac{1}{\eta+\sigma}} \tag{H.13}$$

Using (H.13) and the previously determined equations, one can obtain the stationary values of K, L, Y, I, C.

I Derivation of the Log Linear Model

Wage setting

We begin by stating the loglinear form of equation (3.16), which characterises the dynamics of the aggregate wage index w_t:

$$\hat{w}_t = \psi_w(\chi_w \hat{\pi}_{t-1} - \hat{\pi}_t) + \psi_w \hat{w}_{t-1} + (1-\psi_w)\hat{\tilde{w}}_t \tag{I.1}$$

Given the above result, it is straightforward to show that the first order approximation of (3.61) implies:

$$\hat{s}^w_t = \psi_w \hat{s}^w_{t-1} \tag{I.2}$$

Owing to the full indexation to past inflation restriction we imposed on the steady-state behaviour of real wage contracts, the inefficiency term s^w_t will not have first order effects on any other endogenous variable. Consequently, we can proceed by ignoring its effects on the dynamic system (Schmitt-Grohé and Uribe, 2004). This also enables us to use the aggregate labour demand and supply variables interchangeably.

In loglinear form, equations (3.14) and (3.15) can be written as:

$$\begin{aligned}\hat{x}^1_t = (1-\beta\psi_w)\big[(1-\varphi)\hat{\tilde{w}}_t + \varphi\hat{w}_t + \hat{\lambda}_t + \hat{L}_t\big] \\ + \beta\psi_w\big[(1-\varphi)[\chi_w\hat{\pi}_t - E_t(\hat{\pi}_{t+1})] + (1-\varphi)(\hat{\tilde{w}}_t - E_t\hat{\tilde{w}}_{t+1})\big] + \beta\psi_w E_t \hat{x}_{t+1}\end{aligned} \tag{I.3}$$

$$\begin{aligned}\hat{x}^2_t = (1-\beta\psi_w)\big[\hat{\varpi}_t + \hat{\varsigma}_t - \varphi(1+\eta)(\hat{\tilde{w}}_t - \hat{w}_t) + (1+\eta)\hat{L}_t\big] \\ + \beta\psi_w\big[-\varphi(1+\eta)(\chi_w\hat{\pi}_t - E_t\hat{\pi}_{t+1}) + \varphi(1+\eta)(E_t\hat{\tilde{w}}_{t+1} - \hat{\tilde{w}}_t)\big] + \beta\psi_w\ E_t\hat{x}^2_{t+1}\end{aligned} \tag{I.4}$$

Moreover, we know from (3.13) that x^1 and x^2 are equal up to a first order approximation:

$$\hat{x}^1_t = \hat{x}^2_t \tag{I.5}$$

Hence, we can substract (I.4) from (I.3) to obtain:

$$\begin{aligned}(1-\beta\psi_w)(\hat{\lambda}_t - \eta\hat{L}_t - \hat{\varpi}_t - \hat{\varsigma}_t + \hat{w}_t) + (1-\beta\psi_w)(1+\varphi\eta)(\hat{\tilde{w}}_t - \hat{w}_t) \\ + \beta\psi_w(1+\varphi\eta)[\chi_w\hat{\pi}_t - E_t(\hat{\pi}_{t+1})] + \beta\psi_w(1+\varphi\eta)(\hat{\tilde{w}}_t - E_t\hat{\tilde{w}}_{t+1}) = 0\end{aligned} \tag{I.6}$$

In order to solve for the real wage, we use (I.1) and substitute in the above equation for $\hat{\tilde{w}}_t - \hat{w}_t$ and $\hat{\tilde{w}}_t - E_t\hat{\tilde{w}}_{t+1}$:

$$\hat{\tilde{w}}_t - \hat{w}_t = \frac{\psi_w}{1-\psi_w}(\hat{w}_t - \hat{w}_{t-1}) - \frac{\psi_w}{1-\psi_w}(\chi_w\hat{\pi}_{t-1} - \hat{\pi}_t)$$

$$\hat{\tilde{w}}_t - E_t\hat{\tilde{w}}_{t+1} = -\frac{1}{1-\psi_w}(E_t\hat{w}_{t+1} - \hat{w}_t) + \frac{\psi_w}{1-\psi_w}\big[(1+\chi_w)\hat{\pi}_t - E_t\hat{\pi}_{t+1} - \chi_w\hat{\pi}_{t-1}\big] + \frac{\psi_w}{1-\psi_w}(\hat{w}_t - \hat{w}_{t-1})$$

After multiplying (I.6) by $\frac{1-\psi_w}{\psi_w}$ and some algebra, we obtain:

$$\frac{(1-\psi_w)(1-\beta\psi_w)}{\psi_w}(\hat{\lambda}_t - \eta\hat{L}_t - \hat{\varpi}_t - \hat{\varsigma}_t + \hat{w}_t) + (1+\varphi\eta)(\hat{w}_t - \hat{w}_{t-1}) - (1+\varphi\eta)(\chi_w\hat{\pi}_{t-1} - \hat{\pi}_t) \\ + \beta(1+\varphi\eta)(\chi_w\hat{\pi}_t - E_t\hat{\pi}_{t+1}) - \beta(1+\varphi\eta)(E_t\hat{w}_{t+1} - \hat{w}_t) = 0 \quad \text{(I.7)}$$

Which can be rearranged for $\hat{w}_t$:

$$\hat{w}_t = \frac{\beta}{1+\beta}E_t\hat{w}_{t+1} + \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\chi_w}{1+\beta}\hat{\pi}_{t-1} - \frac{1+\beta\chi_w}{1+\beta}\hat{\pi}_t + \frac{\beta}{1+\beta}E_t\hat{\pi}_{t+1} \\ - \frac{(1-\psi_w)(1-\beta\psi_w)}{\psi_w(1+\varphi\eta)}(\hat{\lambda}_t - \eta\hat{L}_t - \hat{\varpi}_t - \hat{\varsigma}_t + \hat{w}_t) \quad \text{(I.8)}$$

The dynamic wage setting decision rule corresponds to equation (3.72) in section 3.2.

The Domestic Sector NKPC

The derivation of the staggered price setting rules in the goods market is analogous to the previous derivations. We start from by loglinearising the law of the domestic intermediate price level in (3.49):

$$\hat{\tilde{p}}_t^h = \frac{\psi_p}{1-\psi_p}(\hat{\pi}_t^h - \chi_p\hat{\pi}_{t-1}^h) \quad \text{(I.9)}$$

The next step is to obtain the linear recursive equations for v_t^1 and v_t^2, based on (3.47)-(3.48):

$$\hat{v}_t^1 = (1-\beta\psi_p)(\hat{\lambda}_t + \hat{\tilde{p}}_t^h + \hat{Y}_t^h) + \beta\psi_p E_t\hat{v}_{t+1}^1 \\ + \beta\psi_p E_t\left[\hat{\pi}_{t+1}^h - \hat{\pi}_{t+1} + (1-\rho)(\chi_p\hat{\pi}_t^h - \hat{\pi}_{t+1}^h) + \hat{\tilde{p}}_t^h - \hat{\tilde{p}}_{t+1}^h\right]$$

$$\hat{v}_t^2 = (1-\beta\psi_p)(\hat{\lambda}_t + \widehat{\widetilde{MC}}_t^h + \hat{Y}_t^h) + \beta\psi_p E_t[\hat{\pi}_{t+1}^h - \hat{\pi}_{t+1} - \rho(\chi_p\hat{\pi}_t^h - \hat{\pi}_{t+1}^h)] + \beta\psi_p E_t\hat{v}_{t+1}^2$$

We then use the first order equivalence between the two-variables, which can be obtained from (3.46): $\hat{v}_t^1 = \hat{v}_t^2$. Combining the previous identities, gives:

$$(1-\beta\psi_p)(\hat{\tilde{p}}_t^h - \widehat{\widetilde{MC}}_t^h) + \beta\psi_p E_t[\chi_p\hat{\pi}_t^h - \hat{\pi}_{t+1}^h + \hat{\tilde{p}}_t^h - \hat{\tilde{p}}_{t+1}^h] = 0 \quad \text{(I.10)}$$

If the expression obtained for $\hat{\tilde{p}}_t^h$ in (I.9) is substituted for in (I.10), then:

$$(1-\beta\psi_p)\widehat{\widetilde{MC}}_t^h = \frac{\psi_p}{1-\psi_p}(1+\beta\chi_p)\hat{\pi}_t^h - \frac{\psi_p}{1-\psi_p}\chi_p\hat{\pi}_{t-1}^h - \frac{\beta\psi_p}{1-\psi_p}E_t\hat{\pi}_{t+1}^h \quad \text{(I.11)}$$

The last step is to rearrange for π_t^h, which yields the NKPC in the main text.

$$\hat{\pi}_t^h = \frac{\beta}{1+\beta\chi_p}E_t\hat{\pi}_{t+1}^h + \frac{\chi_p}{1+\beta\chi_p}\hat{\pi}_{t-1}^h + \frac{1}{1+\beta\chi_p}\frac{(1-\beta\psi_p)(1-\psi_p)}{\psi_p}\widehat{\widetilde{MC}}_t^h \quad \text{(I.12)}$$

The Import Sector NKPC

The import sector pricing scheme serves as a theoretical tool to account for the low degree of exchange rate pass-through observed in empirical studies. In order to obtain the desired imperfect transmission mechanism of exchange rate changes to consumer prices, one only needs the canonical form of the Calvo adjustment rule, with no indexation.

The forward-looking equation of $\hat{\pi}_t^f$ is just a special case of its domestic sector counterpart, which is recovered after imposing a level of indexation equal to zero ($\chi_p = 0$):

$$\hat{\pi}_t^f = \beta E_t \hat{\pi}_{t+1}^f + \frac{(1-\beta\psi_p)(1-\psi_p)}{\psi_p} \widehat{\hat{MC}}_t^f \tag{I.13}$$

Relative Price Expressions

Up to a first order approximation, the function $J(T_t)$ is related to the terms of trade by:

$$\hat{J}(T_t) = (1-\upsilon)\hat{T}_t \tag{I.14}$$

It is also useful to take first differences of equation (3.23). Then, changes in the terms of trade are equal to the difference between the sector specific inflation rates:

$$\hat{T}_t = \hat{T}_{t-1} + \hat{\pi}_t^f - \hat{\pi}_t^h \tag{I.15}$$

Using the above result, we can obtain an expression for aggregate inflation. In loglinear form, equation (3.25) becomes:

$$\hat{\pi}_t = \upsilon\hat{\pi}_t^h + (1-\upsilon)\hat{\pi}_t^f \tag{I.16}$$

We can apply the result in (I.14) to approximate the relationships in (3.29) and (3.30):

$$\hat{RS}_t = \widehat{\hat{MC}}_t^f + \upsilon\hat{T}_t \tag{I.17}$$

$$\hat{S}_t = \hat{S}_{t-1} + \hat{RS}_t - \hat{RS}_{t-1} + \hat{\pi}_t - \hat{\pi}_t^* \tag{I.18}$$

In order to keep the number of endogenous variables to a minimum, we eliminate the nominal exchange rate from the dynamic system. To this end, we substitute for changes in S in the risk adjusted UIP condition, which becomes:

$$\hat{R}_t^* - \xi\hat{b}_t^F + \hat{\omega}_t + E_t\hat{RS}_{t+1} - \hat{RS}_t + E_t\hat{\pi}_{t+1} - E_t\hat{\pi}_{t+1}^* = \hat{R}_t \tag{I.19}$$

Market Clearing in the Final Good Market

This section reveals the steps behind the derivation of the market clearing conditions in (3.81) and (3.82). In loglinear form, the aggregate production reads as:

$$\hat{Y}_t^h = \frac{K^\alpha L^{1-\alpha}}{Y^h}(\hat{\zeta}_t + \alpha\hat{K}_t + (1-\alpha)\hat{L}_t)$$

Using equation (H.8) in Appendix H, we can rearrange the previous condition as follows:

$$\begin{aligned}\hat{Y}_t^h &= (\frac{K}{Y^h})^\alpha(\frac{L}{Y^h})^{1-\alpha}[\hat{\zeta}_t + \alpha\hat{K}_t + (1-\alpha)\hat{L}_t]\\ &= (\frac{\alpha}{r^k})^\alpha(\frac{1-\alpha}{w})^{1-\alpha}[\hat{\zeta}_t + \alpha\hat{K}_t + (1-\alpha)\hat{L}_t]\\ &= \frac{1}{\widetilde{MC}^h}[\hat{\zeta}_t + \alpha\hat{K}_t + (1-\alpha)\hat{L}_t]\end{aligned}$$

Thus,

$$\hat{Y}_t^h = \frac{\rho}{\rho-1}[\hat{\zeta}_t + \alpha\hat{K}_t + (1-\alpha)\hat{L}_t] \tag{I.20}$$

The market clearing condition for the domestic intermediate good implies:[69]

$$\hat{Y}_t^h = \frac{\upsilon Y}{Y^h}\hat{Z}_t^h + \frac{(1-\upsilon)Y}{Y^h}\hat{Z}_t^x = \upsilon\hat{Z}_t^h + (1-\upsilon)\hat{Z}_t^x \tag{I.21}$$

We need to obtain the intermediate good demand functions from (3.31) and (3.32):

$$\hat{Z}_t^h = \theta(1-\upsilon)\hat{T}_t + \hat{Y}_t \tag{I.22}$$

$$\hat{Z}_t^f = -\theta\upsilon\hat{T}_t + \hat{Y}_t \tag{I.23}$$

and to linearise the export demand function in (3.34):

$$\hat{Z}_t^{\,x} = \hat{\chi}_t + \vartheta\hat{T}_t + \vartheta\hat{\widetilde{MC}}_t^f + \hat{Y}_t^* \tag{I.24}$$

We can combine (I.20)-(I.24) to obtain a production based definition of aggregate output. This is done as follows:

$$\begin{aligned}\hat{Y}_t &= \hat{Z}_t^h - \theta(1-\upsilon)\hat{T}_t\\ &= \frac{\hat{Y}_t^h}{\upsilon} - \frac{1-\upsilon}{\upsilon}\hat{Z}_t^x - \theta(1-\upsilon)\hat{T}_t\\ &= \frac{\rho}{(\rho-1)\upsilon}[\hat{\zeta}_t + \alpha\hat{K}_t + (1-\alpha)\hat{L}_t] - \frac{1-\upsilon}{\upsilon}(\hat{\chi}_t + \vartheta\hat{T}_t + \vartheta\hat{\widetilde{MC}}_t^f + \hat{Y}_t^*) - \theta(1-\upsilon)\hat{T}_t\end{aligned}$$

[69]See equation (3.33).

Hence:

$$\hat{Y}_t = \frac{\rho}{(\rho-1)\upsilon}[\hat{\zeta}_t + \alpha\hat{K}_t + (1-\alpha)\hat{L}_t] - [\frac{1-\upsilon}{\upsilon}\vartheta + \theta(1-\upsilon)]\hat{T}_t - \frac{1-\upsilon}{\upsilon}(\hat{\chi}_t + \vartheta\widehat{\hat{MC}}_t^f + \hat{Y}_t^*) \quad (I.25)$$

which gives equation (3.81) in the main text.

On the other hand, the derivation of expenditure based definition of aggregate output is significantly easier. In loglinear form, equation (3.64) is given by:

$$\hat{Y}_t = \frac{C}{Y}\hat{C}_t + \frac{I}{Y}\hat{I}_t$$

Furthermore, one can derive the steady-state consumption-output and investment-output ratios based on (H.8) and (H.9). After making the relevant substitutions, we obtain:

$$\hat{Y}_t = [1 - \frac{\delta\alpha}{r^k}]\hat{C}_t + \frac{\delta\alpha}{r^k}\hat{I}_t \quad (I.26)$$

The Law of Motion of the Net Foreign Assets Position:

We start from equation (64), which is loglinearised around a steady-state where the trade balance is in equilibrium ($b_t^F = 0$, $Z^{f,d} = Z^{x,d}$).

$$\frac{b_t^F}{R_t^*\Omega(b_t^F)} = \frac{RS_t}{RS_{t-1}}\frac{b_{t-1}^F}{\pi_t^*} + \frac{1}{J(T_t)}Z_t^{x,d} - \frac{T_t}{J(T_t)}Z_t^{f,d}$$

We rearrange the above condition as follows:

$$\frac{1+b_t^F}{R_t^*\Omega(b_t^F)} - \frac{1}{R_t^*\Omega(b_t^F)} = \frac{RS_t}{RS_{t-1}}\frac{(1+b_{t-1}^F)}{\pi_t^*} - \frac{RS_t}{RS_{t-1}}\frac{1}{\pi_t^*} + \frac{1}{J(T_t)}Z_t^{x,d} - \frac{T_t}{J(T_t)}Z_t^{f,d}$$

In order to write the above condition in loglinear form, we use the approximation $\ln(1+b_t^F) \simeq \hat{b}_t^F$, which gives:

$$\frac{\beta}{\pi^*}\hat{b}_t^F + Z^{f,d}(\hat{T}_t - J(\hat{T}_t) + \hat{Z}_t^{f,d}) = \frac{1}{\pi^*}\hat{b}_{t-1}^F + Z^{x,d}(\hat{Z}_t^{x,d} - J(\hat{T}_t))$$

The last step is to substitute for intermediate imports and exports:

$$\hat{Z}_t^{f,d} = -\theta\upsilon\hat{T}_t + \hat{Y}_t$$

$$\hat{Z}_t^{x,d} = \hat{\chi}_t + \vartheta\hat{T}_t + \vartheta\widehat{\hat{MC}}_t^f + \hat{Y}_t^*$$

After straightforward manipulations, it follows that:

$$\frac{\beta}{\pi^*}\hat{b}_t^F = \frac{1}{\pi^*}\hat{b}_{t-1}^F + Z^{f,d}(\hat{\chi}_t + (\vartheta - 1 + \theta\upsilon)\hat{T}_t + \vartheta\hat{\widetilde{MC}}_t^f + \hat{Y}_t^* - \hat{Y}_t) \tag{I.27}$$

J Sensitivity Analysis

Parameter		Baseline	Low price stickiness	Low wage stickiness	Low price indexation	Low wage indexation	Low habit persistence	Low investment adjustment costs
			$\psi_p = 0.1$	$\psi_w = 0.1$	$\chi_p = 0.1$	$\chi_w = 0.1$	$\gamma = 0.1$	$\kappa = 0.1$
Relative risk aversion	σ	1.39	1.38	0.87	1.40	1.41	1.81	1.35
Elasticity of labour substitution^{-1}	η	2.54	2.68	3.41	2.51	2.54	2.60	2.57
Elasticity of substitution	θ	0.57	2.00	0.63	0.56	0.57	0.68	0.58
Investment adjustment cost	κ	3.90	5.71	3.70	3.76	3.91	3.52	
Habit persistence	γ	0.76	0.70	0.66	0.75	0.75		0.84
Indexation wages	χ_w	0.82	0.86	0.79	0.82		0.81	0.81
Calvo wages	ψ_w	0.61	0.58		0.60	0.61	0.62	0.6
Indexation prices	χ_p	0.34	0.72	0.17		0.33	0.34	0.22
Calvo prices	ψ_p	0.79		0.78	0.77	0.79	0.79	0.69
Foreign elasticity of demand	ϑ	0.66	0.68	0.74	0.67	0.66	0.66	0.68
Interest rate smoothing	χ_r	0.69	0.59	0.55	0.67	0.69	0.65	0.68
Inflation feedback coefficient	α_π	1.43	5.01	3.44	1.58	1.41	1.32	1.71
Output feedback coefficient	α_y	0.05	0.06	0.20	0.06	0.05	0.06	0.06
RS feedback coefficient	α_s	0.25	0.34	0.09	0.25	0.25	0.22	0.25
ρ technology shock	ρ_ζ	0.97	0.88	0.92	0.97	0.97	0.97	0.96
ρ preference shock	ρ_ϖ	0.70	0.74	0.65	0.69	0.72	0.90	0.21
ρ labour supply shock	ρ_ς	0.07	0.07	0.37	0.06	0.07	0.07	0.06
ρ risk premium shock	ρ_ω	0.46	0.66	0.62	0.45	0.46	0.43	0.43
ρ foreign demand shock	ρ_χ	0.56	0.81	0.50	0.57	0.56	0.57	0.49
ρ investment technology shock	$\rho_\varkappa$	0.10	0.18	0.16	0.11	0.10	0.10	0.81
ρ monetary policy shock	ρ_ν	0.26	0.72	0.75	0.30	0.26	0.28	0.16
σ technology shock	σ_ζ	0.033	0.04	0.031	0.033	0.033	0.031	0.036
σ preference shock	σ_ϖ	0.11	0.08	0.05	0.10	0.11	0.05	0.16
σ labour supply shock	σ_ς	0.97	0.80	0.16	0.95	0.98	1.07	1.01
σ risk premium shock	σ_ω	0.007	0.008	0.009	0.007	0.007	0.008	0.006
σ foreign demand shock	σ_χ	0.06	0.06	0.05	0.06	0.06	0.06	0.06
σ investment technology shock	$\sigma_\varkappa$	0.30	0.40	0.25	0.29	0.30	0.30	0.11
σ monetary policy shock	σ_ν	0.0039	0.007	0.0065	0.004	0.0039	0.004	0.0042
Log marginal data density		1195	1173	1173	1196.3	1192	1173.3	1141.5

Table J.1: The empirical relevance of nominal and real frictions in the DSGE model. Posterior mode estimates in the Czech Republic.

Parameter		Baseline	Low price stickiness $\psi_p = 0.1$	Low wage stickiness $\psi_w = 0.1$	Low price indexation $\chi_p = 0.1$	Low wage indexation $\chi_w = 0.1$	Low habit persistence $\gamma = 0.1$	Low investment adjustment costs $\kappa = 0.1$
Relative risk aversion	σ	0.97	1.06	0.93	0.90	0.97	1.74	0.87
Elasticity of labour substitution^{-1}	η	2.83	3.05	4.71	2.82	2.83	2.72	2.79
Elasticity of substitution	θ	0.37	4.24	1.67	1.90	0.37	0.37	0.45
Investment adjustment cost	κ	2.55	3.65	1.59	1.80	2.57	2.11	
Habit persistence	γ	0.84	0.80	0.69	0.76	0.84		0.84
Indexation wages	χ_w	0.80	0.88	0.79	0.84		0.80	0.79
Calvo wages	ψ_w	0.75	0.63		0.68	0.76	0.72	0.70
Indexation prices	χ_p	0.73	0.83	0.36		0.70	0.74	0.76
Calvo prices	ψ_p	0.84		0.70	0.84	0.84	0.83	0.82
Foreign elasticity of demand	ϑ	0.63	0.67	0.65	0.57	0.63	0.64	0.65
Interest rate smoothing	χ_r	0.93	0.95	0.83	0.87	0.93	0.95	0.91
Inflation feedback coefficient	α_π	5.24	8.28	9.97	8.00	5.25	5.89	6.97
Output feedback coefficient	α_y	0.16	0.10	0.06	0.14	0.15	0.20	0.25
RS feedback coefficient	α_s	0.22	0.22	0.16	0.32	0.22	0.22	0.20
ρ technology shock	ρ_ζ	0.95	0.85	0.78	0.85	0.95	0.96	0.97
ρ preference shock	ρ_ϖ	0.17	0.17	0.14	0.22	0.16	0.82	0.10
ρ labour supply shock	ρ_ς	0.54	0.39	0.15	0.42	0.56	0.48	0.37
ρ risk premium shock	ρ_ω	0.13	0.12	0.13	0.38	0.13	0.13	0.12
ρ foreign demand shock	ρ_χ	0.48	0.87	0.84	0.31	0.48	0.45	0.36
ρ investment technology shock	$\rho_\varkappa$	0.07	0.07	0.65	0.38	0.07	0.07	0.86
ρ monetary policy shock	ρ_ν	0.29	0.36	0.71	0.73	0.29	0.26	0.56
σ technology shock	σ_ζ	0.024	0.024	0.026	0.024	0.024	0.024	0.024
σ preference shock	σ_ϖ	0.09	0.08	0.05	0.06	0.09	0.05	0.08
σ labour supply shock	σ_ς	0.57	0.31	0.12	0.43	0.58	0.46	0.51
σ risk premium shock	σ_ω	0.004	0.004	0.004	0.004	0.004	0.004	0.004
σ foreign demand shock	σ_χ	0.05	0.03	0.04	0.05	0.05	0.04	0.04
σ investment technology shock	$\sigma_\varkappa$	0.27	0.31	0.13	0.20	0.27	0.22	0.09
σ monetary policy shock	σ_ν	0.0024	0.0024	0.0029	0.0024	0.0024	0.0024	0.0024
Log marginal data density		1463.3	1403.8	1404.2	1391.8	1461.6	1445.7	1442.7

Table J.2: The empirical relevance of nominal and real frictions in the DSGE model. Posterior mode estimates in Austria.

Parameter		Prior distribution			Posterior distribution Czech Republic			Posterior distribution Austria		
		Density	Mean	S.d./d.f.*	Base	Mean	[5% − 95%]	Base	Mean	[5% − 95%]
Relative risk aversion	σ	Normal	1	0.3	1.3893	1.3785	[1.01-1.75]	1.0212	0.8997	[0.45-1.35]
Elasticity of labour substitution^{-1}	η	Gamma	3	0.4	2.6704	2.7386	[2.15-3.31]	2.9247	2.9795	[2.31-3.61]
Elasticity of substitution	θ	Gamma	1	0.5	0.6585	0.6431	[0.30-0.98]	0.4277	0.4058	[0.13-0.65]
Investment adjustment cost	κ	Normal	4	1.5	4.0738	3.7782	[2.64-4.76]	2.6746	2.7260	[1.81-3.63]
Habit persistence	γ	U[0,1]	0.5	0.29	0.7854	0.7298	[0.61-0.86]	0.8275	0.8725	[0.81-0.94]
Indexation wages	χ_w	Calibrated	0.7	-	0.7504	-	-	0.7234	-	-
Calvo wages	ψ_w	U[0,1]	0.5	0.29	0.6209	0.4454	[0.36-0.53]	0.7513	0.7678	[0.69-0.85]
Indexation prices	χ_p	U[0,1]	0.5	0.29	0.3567	0.1539	[0-0.29]	0.7239	0.6663	[0.49-0.85]
Calvo prices	ψ_p	U[0,1]	0.5	0.29	0.7919	0.7577	[0.71-0.81]	0.8411	0.8549	[0.83-0.88]
Foreign elasticity of demand	ϑ	Beta	0.6	0.1	0.6455	0.6559	[0.52-0.79]	0.6109	0.6090	[0.48-0.75]
Interest rate smoothing	χ_r	Beta	0.5	0.2	0.6919	0.6644	[0.55-0.78]	0.9334	0.9404	[0.92-0.97]
Inflation feedback coefficient	α_π	Gamma	2	1	1.4687	1.8535	[1.40-2.29]	6.1837	7.0561	[5.51-8.64]
Output feedback coefficient	α_y	Gamma	0.25	0.1	0.0588	0.0781	[0.04-0.12]	0.1759	0.1913	[0.11-0.28]
RS feedback coefficient	α_s	Gamma	0.25	0.1	0.2532	0.2346	[0.13-0.34]	0.2600	0.2549	[0.10-0.42]
ρ technology shock	ρ_ζ	Beta	0.5	0.2	0.9562	0.9528	[0.92-0.98]	0.9389	0.9387	[0.91-0.97]
ρ preference shock	ρ_ϖ	Beta	0.5	0.2	0.6517	0.6640	[0.53-0.8]	0.2111	0.1801	[0.04-0.31]
ρ labour supply shock	ρ_ς	Beta	0.5	0.2	0.0913	0.1070	[0.02-0.19]	0.5039	0.5121	[0.37-0.66]
ρ risk premium shock	ρ_ω	Beta	0.5	0.2	0.4223	0.4680	[0.26-0.68]	0.1643	0.1647	[0.03-0.28]
ρ foreign demand shock	ρ_χ	Beta	0.5	0.2	0.5433	0.5121	[0.42-0.61]	0.4509	0.4634	[0.33-0.60]
ρ investment technology shock	$\rho_\varkappa$	Beta	0.5	0.2	0.1345	0.1416	[0.02-0.25]	0.1081	0.1015	[0.01-0.18]
ρ monetary policy shock	ρ_ν	Beta	0.5	0.2	0.2692	0.3505	[0.11-0.58]	0.3313	0.3279	[0.10-0.53]
σ technology shock	σ_ζ	IGamma	0.2	2	0.0338	0.0340	[0.03-0.04]	0.026	0.0263	[0.024-0.029]
σ preference shock	σ_ϖ	IGamma	0.2	2	0.1329	0.1013	[0.06-0.14]	0.0952	0.1118	[0.07-0.15]
σ labour supply shock	σ_ς	IGamma	1	2	1.1874	0.4672	[0.28-0.64]	0.6856	0.8518	[0.28-1.5]
σ risk premium shock	σ_ω	IGamma	0.02	2	0.0088	0.0080	[0.005-0.011]	0.0038	0.0038	[0.003-0.005]
σ foreign demand shock	σ_χ	IGamma	0.2	2	0.0637	0.0632	[0.05-0.07]	0.0507	0.0528	[0.044-0.062]
σ investment technology shock	$\sigma_\varkappa$	IGamma	0.5	2	0.3229	0.2918	[0.22-0.37]	0.2833	0.2880	[0.20-0.37]
σ monetary policy shock	σ_ν	IGamma	0.02	2	0.0040	0.0044	[0.003-0.005]	0.0025	0.0025	[0.002-0.003]

* Note: for the inverted gamma distribution, the degrees of freedom are reported.

Table J.3: Sensitivity analysis of the posterior inference. The effects of alternative priors

References

Abiad, A., D. Leigh, and A. Mody (2007). International Finance and Income Convergence: Europe is Different. *IMF Working Papers*, 1–36.

Acemoglu, D. and F. Zilibotti (2001). Productivity Differences. *The Quarterly Journal of Economics 116*(2), 563–606.

Adolfson, M., S. Laséen, J. Lindé, and M. Villani (2007). Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through. *Journal of International Economics 72*(2), 481–511.

Aguiar, M. and G. Gopinath (2007). Emerging Market Business Cycles: The Cycle Is the Trend. *Journal of Political Economy 115*(1).

Altig, D., L. Christiano, M. Eichenbaum, and J. Linde (2005). Firm-Specific Capital, Nominal Rigidities and the Business Cycle. Technical report, National Bureau of Economic Research.

Altissimo, F., M. Ehrmann, and F. Smets (2006). Inflation Persistence and Price-Setting Behaviour in the Euro Area - A Summary of the IPN Evidence. *ECB Occasional Paper* (46).

Amato, J. D. and S. Gerlach (2001). Modelling the Transmission Mechanism of Monetary Policy in Emerging Market Countries Using Prior Information. *BIS Papers 18*, 264–272.

Ambler, S., A. Dib, and N. Rebei. Optimal Taylor Rules in an Estimated Model of a Small Open Economy. Bank of Canada Working Paper.

An, S. and F. Schorfheide (2007). Bayesian Analysis of DSGE Models. *Econometric Reviews 26*(2-4), 113–172.

Andrés, J., J. David López-Salido, and J. Vallés (2006). Money in an Estimated Business Cycle Model of the Euro Area. *The Economic Journal 116*(511), 457–477.

Angeloni, I., M. Flad, and F. Mongelli (2007). Monetary Integration of the New EU Member States: What Sets the Pace of Euro Adoption? *JCMS: Journal of Common Market Studies 45*(2), 367–409.

Anzuini, A. and A. Levy (2007). Monetary Policy Shocks in the New EU Members: A VAR Approach. *Applied Economics 39*(9), 1147–1161.

Aoki, K. (2001). Optimal Monetary Policy Responses to Relative-Price Changes. *Journal of Monetary Economics 48*(1), 55–80.

Arratibel, O., F. Heinz, R. Martin, M. Przybyla, L. Rawdanowicz, R. Serafini, and T. Zumer (2007). Determinants of Growth in the Central and Eastern European EU Member States - A Production Function Approach. *European Central Bank, Occasional Paper Series*.

Asea, P. and E. Mendoza (1994). The Balassa-Samuelson Model: A General-Equilibrium Appraisal. *Review of International Economics 2*(3), 244–267.

Atkeson, A. and A. Burstein (2008). Pricing-to-Market, Trade Costs, and International Relative Prices. *The American Economic Review 98*(5), 1998–2031.

Bacchetta, P. and E. Van Wincoop (2000). Does Exchange-Rate Stability Increase Trade and Welfare? *American Economic Review*, 1093–1109.

Bakker, B. B. and A.-M. Gulde (2010). The Credit Boom in the EU New Member States: Bad Luck or Bad Policies? *IMF Working Papers*, 1–45.

Balassa, B. (1964). The Purchasing-Power Parity Doctrine: A Reappraisal. *The Journal of Political Economy 72*(6), 584–596.

Barro, R. and X. Sala-i Martin (1990). Economic Growth and Convergence across the United States. Technical report, National Bureau of Economic Research.

Basu, S., J. Fernald, and M. Kimball (2004). Are Technology Improvements Contractionary? Technical report, National Bureau of Economic Research.

Batini, N., P. Levine, and J. Pearlman (2007). Monetary Rules in Emerging Economies with Financial Market Imperfections. NBER Working Paper.

Batini, N., P. Levine, and J. Pearlman (2009). Monetary and Fiscal Rules in an Emerging Small Open Economy. *IMF Working Papers*, 1–78.

Baumöl, W. (1967). Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis. *The American Economic Review 57*(3), 415–426.

Baumöl, W. and W. Bowen (1965). On the Performing Arts: The Anatomy of Their Economic Problems. *The American Economic Review 55*(1/2), 495–502.

Bayoumi, T. and B. Eichengreen (1993). Shocking Aspects of European Monetary Integration. In *Adjustment and Growth in the European Monetary Union*, pp. 193–229. Cambridge University Press.

Bayoumi, T., M. Kumhof, D. Laxton, and K. Naknoi (2004). Exchange Rate Regimes, International Linkages, and the Macroeconomic Performance of the New Member States. *The New EU Member States Convergence and Stability*, 75.

Bazaraa, M. S., H. D. Sherali, and C. M. Shetty (2006). *Nonlinear Programming: Theory And Algorithms*. Wiley-interscience.

Begg, D. (1998). Pegging Out: Lessons from the Czech Exchange Rate Crisis. *Journal of Comparative Economics 26*(4), 669–690.

Begg, D., B. Eichengreen, J. von Hagen, L. Halpern, and C. Wyplosz (2003). *Sustainable Regimes of Capital Movements in Accession Countries.* Centre for Economic Policy Research.

Begg, I. (2006). Real Convergence and EMU Enlargement: the Time Dimension of Fit with the Euro Area. In K. Dyson (Ed.), *Enlarging the Euro Area: External Empowerment and Domestic Transformation in East Central Europe.* Oxford University Press.

Benczúr, P. and A. Rátfai (2010). Economic Fluctuations in Central and Eastern Europe: The Facts. *Applied Economics 42*(25), 3279–3292.

Benigno, G. and P. Benigno (2003). Price Stability in Open Economies. *The Review of Economic Studies 70*(4), 743–764.

Benigno, G. and C. Thoenissen (2003). Equilibrium Exchange Rates and Supply-Side Performance. *The Economic Journal 113*(486), C103–C124.

Benigno, G. and C. Thoenissen (2008). Consumption and Real Exchange Rates with Incomplete Markets and Non-Traded Goods. *Journal of International Money and Finance 27*(6), 926–948.

Benigno, P. (2009). Price Stability with Imperfect Financial Integration. *Journal of Money, Credit and Banking 41*(s1), 121–149.

Berger, J. (1985). *Statistical Decision Theory and Bayesian Analysis.* Springer.

Berger, J. O., E. Moreno, L. R. Pericchi, M. J. Bayarri, J. M. Bernardo, J. A. Cano, J. De la Horra, J. Martín, D. Ríos-Insúa, B. Betrò, et al. (1994). An Overview of Robust Bayesian Analysis. *Test 3*(1), 5–124.

Bergin, P. (2003). Putting the New Open Economy Macroeconomics to a Test. *Journal of International Economics 60*(1), 3–34.

Bergin, P. (2006). How Well Can the New Open Economy Macroeconomics Explain the Exchange Rate and Current Account? *Journal of International Money and Finance 25*(5), 675–701.

Bergin, P., H. Shin, and I. Tchakarov (2007). Does Exchange Rate Variability Matter for Welfare? A Quantitative Investigation of Stabilization Policies. *European Economic Review 51*(4), 1041–1058.

Betts, C. and M. Devereux (2000). Exchange Rate Dynamics in a Model of Pricing-to-Market. *Journal of International Economics 50*(1), 215–244.

Bijsterbosch, M. and M. Kolasa (2010). FDI and Productivity Convergence in Central and Eastern Europe: An Industry-Level Investigation. *Review of World Economics 145*(4), 689–712.

Bini Smaghi, L. (2007). Real Convergence in Central, Eastern and South-Eastern Europe. In *Speech at the ECB Conference on Central, Eastern and South-Eastern Europe*.

Blanchard, O. (1997). *The Economics of Post-Communist Transition*. Oxford University Press.

Blanchard, O. J., H. Faruqee, M. Das, K. J. Forbes, and L. L. Tesar (2010). The Initial Impact of the Crisis on Emerging Market Countries [with Comments and Discussion]. *Brookings Papers on Economic Activity*, 263–323.

Boivin, J., M. P. Giannoni, and B. Mojon (2008). How Has the Euro Changed the Monetary Transmission? Technical report, National Bureau of Economic Research.

Borensztein, E., J. De Gregorio, and J. Lee (1998). How Does Foreign Direct Investment Affect Economic Growth? *Journal of International Economics 45*(1), 115–135.

Borys, M., É. Polgár, and A. Zlate (2009). Real Convergence in Central, Eastern and South-Eastern Europe: A Production Function Approach. In R. Martin and A. Winkler (Eds.), *Real Convergence in Central, Eastern and South-Eastern Europe*, pp. 27–64.

Borys, M. M., R. Horváth, and M. Franta (2009). The Effects of Monetary Policy in the Czech Republic: An Empirical Study. *Empirica 36*(4), 419–443.

Brooks, S. and A. Gelman (1998). General Methods for Monitoring Convergence of Iterative Simulations. *Journal of Computational and Graphical Statistics 7*(4), 434–455.

Buiter, W. (2000). *Optimal Currency Areas: Why Does the Exchange Rate Regime Matter?(With an Application to UK Membership in EMU)*. Centre for Economic Performance, London School of Economics and Political Science.

Campa, J. and L. Goldberg (2006). Distribution Margins, Imported Inputs, and the Sensitivity of the CPI to Exchange Rates. *NBER Working Paper Series 12121*.

Campa, J. M. and L. S. Goldberg (2005). Exchange Rate Pass-Through into Import Prices. *Review of Economics and Statistics 87*(4), 679–690.

Canova, F. (2007). *Methods for Applied Macroeconomic Research*. Princeton University Press.

Canova, F. and L. Sala (2009). Back to Square One: Identification Issues in DSGE Models. *Journal of Monetary Economics 56*(4), 431–449.

Canzoneri, M., R. Cumby, and B. Diba (2005). The Need for International Policy Coordination: What's Old, What's New, What's Tet to Come? *Journal of International Economics 66*(2), 363–384.

Carone, G., C. Denis, K. McMorrow, G. Mourre, and R. Werner (2006). Long-Term Labour Productivity and GDP Projections for EU25 Member States: A Production Function Approach. *European Commission, Economic Paper* (253).

Castillo, P., C. Montoro, and V. Tuesta (2006). An Estimated Stochastic General Equilibrium Model with Partial Dollarization: a Bayesian Approach. *Open Economies Review*, 1–49.

Cerutti, E., G. Dell'Ariccia, and M. S. Martinez Peria (2007). How Banks Go Abroad: Branches or Subsidiaries? *Journal of Banking & Finance 31*(6), 1669–1692.

Cespedes, L., R. Chang, and A. Velasco (2004). Balance Sheets and Exchange Rate Policy. *The American Economic Review 94*(4), 1183–1193.

Chari, V., P. Kehoe, and E. McGrattan (2002). Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates? *The Review of Economic Studies 69*(3), 533–563.

Chari, V., P. Kehoe, and E. McGrattan (2004). *A Critique of Structural VARs Using Real Business Cycle Theory*. Federal Reserve Bank of Minneapolis, Research Department.

Christiano, L., M. Eichenbaum, and C. Evans (2005). Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*.

Christiano, L., R. Motto, and M. Rostagno (2007). Notes on Ramsey-Optimal Monetary Policy. Mimeo, Northwestern University.

Christiano, L., R. Motto, and M. Rostagno (2008). Shocks, Structures or Monetary Policies? The Euro Area and US after 2001. *Journal of Economic Dynamics and Control 32*(8), 2476–2506.

Clarida, R., J. Galí, and M. Gertler (1999). The Science of Monetary Policy: A New Keynesian Perspective. *Journal of Economic Literature 37*, 1661–1707.

Clarida, R., J. Galí, and M. Gertler (2001). Optimal Monetary Policy in Open versus Closed Economies: An Integrated Approach. *The American Economic Review 91*(2), 248–252.

Cole, H. and M. Obstfeld (1991). Commodity Trade and International Risk Sharing: How Much Do Financial Markets Matter? *Journal of Monetary Economics 28*(1), 3–24.

Collard, F. and H. Dellas (2007). Technology Shocks and Employment. *The Economic Journal 117*(523), 1436–1459.

Cook, D. and M. B. Devereux (2006). External Currency Pricing and the East Asian Crisis. *Journal of International Economics 69*(1), 37–63.

Cooley, T. and E. Prescott (1995). Economic Growth and Business Cycles. *Frontiers of Business Cycle Research*, 1–38.

Coricelli, F., B. Jazbec, and I. Masten (2006). Exchange Rate Pass-Through in EMU Acceding Countries: Empirical Analysis and Policy Implications. *Journal of Banking and Finance 30*(5), 1375–1391.

Corsetti, G. (2008). A Modern Reconsideration of the Theory of Optimal Currency Areas. European University Institute Working Paper.

Corsetti, G., L. Dedola, and S. Leduc (2008a). High Exchange-Rate Volatility and Low Pass-Through. *Journal of Monetary Economics 55*(6), 1113–1128.

Corsetti, G., L. Dedola, and S. Leduc (2008b). International Risk Sharing and the Transmission of Productivity Shocks. *Review of Economic Studies 75*(2), 443–473.

Corsetti, G., L. Dedola, and S. Leduc (2010). Optimal Monetary Policy in Open Economies. In B. M. Friedman and W. Michael (Eds.), *Handbook of Monetary Economics*, Volume 3, pp. 861–933. Elsevier.

Corsetti, G. and P. Pesenti (2001). Welfare and Macroeconomic Interdependence. *Quarterly Journal of Economics 116*(2), 421–445.

Corsetti, G. and P. Pesenti (2005). International Dimensions of Optimal Monetary Policy. *Journal of Monetary Economics 52*(2), 281–305.

Cull, R., J. Matesova, and M. Shirley (2002). Ownership and the Temptation to Loot: Evidence from Privatized Firms in the Czech Republic. *Journal of Comparative Economics 30*(1), 1–24.

Czech National Bank and the Czech Ministry of Finance (2011). Assessement of the Fulfilment of the Maastricht Convergence Criteria and the Degree of Economic Alignment of the Czech Republic with the Euro Area.

Czech National Bank and the Government of the Czech Republic (2007). The Czech Republic's Updated Euro Area Accession Strategy.

Darvas, Z. (2001). Exchange Rate Pass-Through and Real Exchange Rate in EU Candidate Countries. Technical report, Discussion paper Series 1/Volkswirtschaftliches Forschungszentrum der Deutschen Bundesbank.

Darvas, Z. and G. Szapáry (2008). Business Cycle Synchronization in the Enlarged EU. *Open Economies Review 19*(1), 1–19.

De Gregorio, J., A. Giovannini, and H. Wolf (1994). International Evidence on Tradables and Nontradables Inflation. *European Economic Review 38*(6), 1225–1244.

De Haas, R. and I. Van Lelyveld (2006). Foreign Banks and Credit Stability in Central and Eastern Europe. A Panel Data Analysis. *Journal of Banking & Finance 30*(7), 1927–1952.

De Paoli, B. (2009a). Monetary Policy and Welfare in a Small Open Economy. *Journal of International Economics 77*(1), 11–22.

De Paoli, B. (2009b). Monetary Policy under Alternative Asset Market Structures: The Case of a Small Open Economy. *Journal of Money, Credit and Banking 41*(7), 1301–1330.

Dedola, L. and S. Neri (2007). What Does a Technology Shock Do? A VAR Analysis with Model-Based Sign Restrictions. *Journal of Monetary Economics 54*(2), 512–549.

Del Negro, M. and F. Schorfheide (2008). Forming Priors for DSGE Models (And How It Affects the Assessment of Nominal Rigidities). *Journal of Monetary Economics 55*(7), 1191–1208.

Del Negro, M., F. Schorfheide, F. Smets, and R. Wouters (2007). On the Fit of New Keynesian Models. *Journal of Business and Economic Statistics 25*(2), 123–143.

Delampady, M. and J. O. Berger (1990). Lower Bounds on Bayes Factors for Multinomial Distributions, with Application to Chi-Squared Tests of Fit. *The Annals of Statistics*, 1295–1316.

Dellas, H. and G. Tavlas (2009). An Optimum-Currency-Area Odyssey. *Journal of International Money and Finance 28*(7), 1117–1137.

Devereux, M. and C. Engel (2003). Monetary Policy in the Open Economy Revisited: Price Setting and Exchange-Rate Flexibility. *Review of Economic Studies 70*(4), 765–783.

Devereux, M., P. Lane, and J. Xu (2006). Exchange Rates and Monetary Policy in Emerging Market Economies. *The Economic Journal 116*(511), 478–506.

Devereux, M. B. and C. Engel (2002). Exchange Rate Pass-Through, Exchange Rate Volatility, and Exchange Rate Disconnect. *Journal of Monetary economics 49*(5), 913–940.

DiCecio, R. and E. Nelson (2010). Euro Membership as a UK Monetary Policy Option: Results from a Structural Model. In A. Alesina and F. Giavazzi (Eds.), *Europe and the Euro*, pp. 415–439. University of Chicago Press.

Djankov, S. and P. Murrell (2002). Enterprise Restructuring in Transition: A Quantitative Survey. *Journal of Economic Literature 40*(3), 739–792.

Driver, R., P. Sinclair, and C. Thoenissen (2005). *Exchange Rates, Capital Flows and Policy.* Routledge.

Dupor, B., J. Han, and Y.-C. Tsai (2009). What Do Technology Shocks Tell Us About the New Keynesian Paradigm? *Journal of Monetary Economics 56*(4), 560–569.

Dyson, K. (2006). *Enlarging the Euro Area: External Empowerment and Domestic Transformation in East Central Europe.* Oxford University Press.

Edge, R., T. Laubach, and J. Williams (2007). Learning and Shifts in Long-Run Productivity Growth. *Journal of Monetary Economics 54*(8), 2421–2438.

Edge, R. M., T. Laubach, and J. C. Williams (2005). Monetary Policy and Shifts in Long Run Productivity Growth. In *International Research Forum on Monetary Policy: Third Conference, ECB, May*, Volume 20.

Égert, B., L. Halpern, and R. MacDonald (2006). Equilibrium Exchange Rates in Transition Economies: Taking Stock of the Issues. *Journal of Economic Surveys 20*(2), 257–324.

Elekdağ, S. and I. Tchakarov (2007). Balance Sheets, Exchange Rate Policy, and Welfare. *Journal of economic dynamics and control 31*(12), 3986–4015.

Engel, C. (1999). Accounting for US Real Exchange Rate Changes. *Journal of Political Economy 107*(3), 507–538.

Engel, C. (2011). Currency Misalignments and Optimal Monetary Policy: A Reexamination. *American Economic Review 101*(6), 2796–2822.

Erceg, C., D. Henderson, and A. Levin (2000). Optimal Monetary Policy with Staggered Wage and Price Contracts. *Journal of Monetary Economics 46*(2), 281–313.

European Union (2010). Consolidated Version of the Treaty on the Functioning of the European Union. *Official Journal of the European Union C 83/49*.

Fabiani, S., M. Druant, I. Hernando, C. Kwapil, B. Landau, C. Loupias, F. Martins, T. Mathä, R. Sabbatini, H. Stahl, et al. (2005). The Pricing Behaviour of Firms in the Euro Area: New Survey Evidence. *ECB Working Paper No. 535*.

Fabrizio, S., D. Leigh, and A. Mody (2010). The Second Transition: Eastern Europe in Perspective. *Five Years of an Enlarged EU*, 191–220.

Faia, E. and T. Monacelli (2008). Optimal Monetary Policy in a Small Open Economy with Home Bias. *Journal of Money, Credit and Banking 40*(4), 721–750.

Fasolo, A. (2010). *Optimal Monetary and Fiscal Policy for Small Open and Emerging Economies.* Ph. D. thesis, Duke University.

Fernández-Villaverde, J. (2010). The Econometrics of DSGE Models. *SERIES: Journal of the Spanish Economic Association 1*(1), 3–49.

Fernández-Villaverde, J., P. Guerrón-Quintana, and J. Rubio-Ramírez (2010). The New Macroeconometrics: A Bayesian Approach. *The Oxford Handbook of Applied Bayesian Analysis*, 366.

Fernández-Villaverde, J., J. Rubio-Ramírez, T. Sargent, and M. Watson (2007). ABCs (and Ds) of Understanding VARs. *The American Economic Review 97*(3), 1021–1026.

Fidrmuc, J. and I. Korhonen (2003). Similarity of Supply and Demand Shocks between the Euro Area and the CEECs. *Economic Systems 27*(3), 313–334.

Francis, N. and V. A. Ramey (2005). Is the Technology-Driven Real Business Cycle Hypothesis Dead? Shocks and Aggregate Fluctuations Revisited. *Journal of Monetary Economics 52*(8), 1379–1399.

Frankel, J. (2005). Real Convergence and Euro Adoption in Central and Eastern Europe: Trade and Business Cycle Correlations as Endogenous Criteria for Joining the EMU. In S. Schadler (Ed.), *Euro Adoption in Central and Eastern Europe: Opportunities and Challenges*. International Monetary Fund.

Frenkel, M. and C. Nickel (2005). How Symmetric Are the Shocks and the Shock Adjustment Dynamics between the Euro Area and Central and Eastern European Countries? *Journal of Common Market Studies 43*(1), 53–74.

Friedman, M. (1953). *Essays in Positive Economics*. University of Chicago Press.

Fuchs, V. (1968). *The Service Economy*. National Bureau of Economic Research, Inc.

Fuhrer, J. and G. Moore (1995). Inflation Persistence. *The Quarterly Journal of Economics 110*(1), 127–159.

Furceri, D. and G. Karras (2008). Business-Cycle Synchronization in the EMU. *Applied Economics 40*(12), 1491–1501.

Galí, J. (1999). Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations? *American Economic Review 89*(1), 249–271.

Galí, J. (2008). *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework*. Princeton University Press.

Galı, J., J. Lopez-Salido, and J. Valles (2003). Technology Shocks and Monetary Policy: Assessing the Fed's Performance. *Journal of Monetary Economics 50*(4), 723–743.

Gali, J. and T. Monacelli (2005). Monetary Policy and Exchange Rate Volatility in a Small Open Economy. *The Review of Economic Studies 72*(3), 707.

Galí, J. and P. Rabanal (2005). Technology Shocks and Aggregate Fluctuations: How Well Does the Real Business Cycle Model Fit Postwar US Data? In *NBER Macroeconomics Annual 2004, Volume 19*, pp. 225–318. MIT Press.

García-Solanes, J. and R. María-Dolores (2008). The New Member States and the Process Towards EMU. *Review of Development Economics 12*(3), 655–667.

Gelman, A., J. Carlin, H. Stern, and D. Rubin (2003). *Bayesian Data Analysis*. Chapman & Hall/CRC.

Gertler, M., S. Gilchrist, and F. M. Natalucci (2007). External Constraints on Monetary Policy and the Financial Accelerator. *Journal of Money, Credit and Banking 39*(2-3), 295–330.

Geweke, J. (1989). Bayesian Inference in Econometric Models Using Monte Carlo Integration. *Econometrica: Journal of the Econometric Society*, 1317–1339.

Geweke, J. (1999). Using Simulation Methods for Bayesian Econometric Models: Inference, Development, and Communication. *Econometric Reviews 18*(1), 1–73.

Ghironi, F. (2006). Macroeconomic Interdependence under Incomplete Markets. *Journal of International Economics 70*(2), 428–450.

Ghironi, F. (2008). The Role of Net Foreign Assets in a New Keynesian Small Open Economy Model. *Journal of Economic Dynamics and Control 32*(6), 1780–1811.

Giannone, D., M. Lenza, and L. Reichlin (2010). Business Cycles in the Euro Area. In *Europe and the Euro*, pp. 141–167. University of Chicago Press.

Goldberg, L. S. and C. Tille (2008). Vehicle Currency Use in International Trade. *Journal of International Economics 76*(2), 177–192.

Goldberg, P. K. and M. M. Knetter (1997). Goods Prices and Exchange Rates: What Have We Learned? *Journal of Economic Literature 35*(3), 1243–1272.

Gopinath, G., O. Itshoki, and R. Rigobon (2010). Currency Choice and Exchange Rate Pass-Through. *The American economic review 100*(1), 304–336.

Greenwood, J., Z. Hercowitz, and G. Huffman (1988). Investment, Capacity Utilization, and the Real Business Cycle. *The American Economic Review*, 402–417.

Guerron-Quintana, P. and J. Nason (2012). Bayesian Estimation of DSGE Models. FRB of Philadelphia Working Paper.

Hall, G. J. (1996). Overtime, Effort, and the Propagation of Business Cycle Shocks. *Journal of Monetary Economics 38*(1), 139–160.

Hamilton, J. (1994). *Time Series Analysis*. Princeton, NJ: Princeton University Press.

Høj, J., M. Jimenez, M. Maher, G. Nicoletti, and M. Wise (2007). Product Market Competition in the OECD Countries: Taking Stock and Moving Forward. *OECD Economics Department Working Papers*.

Ireland, P. (2004a). A Method for Taking Models to the Data. *Journal of Economic Dynamics and Control 28*(6), 1205–1226.

Ireland, P. (2004b). Technology Shocks in the New Keynesian Model. *The Review of Economics and Statistics 86*(4), 923–936.

Iskrev, N. (2010). Local Identification in DSGE Models. *Journal of Monetary Economics 57*(2), 189–202.

Jarociński, M. (2010). Responses to Monetary Policy Shocks in the East and the West of Europe: A Comparison. *Journal of Applied Econometrics 25*(5), 833–868.

Jenish, N. (2008). *Essays in Open Economy Macroeconomics*. Ph. D. thesis, Central European University, Budapest.

Johnson, S., R. Porta, F. Lopez-de Silanes, and A. Shleifer (2000). Tunnelling. Technical report, National Bureau of Economic Research.

Jonas, J. (2006). Euro Adoption and Maastricht Criteria: Rules or Discretion? *Economic Systems 30*(4), 328–345.

Jonas, J. and F. S. Mishkin (2004). Inflation Targeting in Transition Economies Experience and Prospects. In *The Inflation-Targeting Debate*, pp. 353–422. University of Chicago Press.

Juillard, M. and F. Pelgrin (2007). Computing Optimal Policy in a Timeless-Perspective: An Application to a Small-Open Economy.

Justiniano, A. and B. Preston (2010a). Can Structural Small Open-Economy Models Account for the Influence of Foreign Disturbances? *Journal of International Economics 81*(1), 61–74.

Justiniano, A. and B. Preston (2010b). Monetary Policy and Uncertainty in an Empirical Small Open-Economy Model. *Journal of Applied Econometrics 25*(1), 93–128.

Karam, P., D. Laxton, D. Rose, and N. Tamirisa (2008). The Macroeconomic Costs and Benefits of Adopting the Euro. *IMF Staff Papers 55*(2), 339–355.

Kass, R. E. and A. E. Raftery (1995). Bayes Factors. *Journal of the American Statistical Association 90*(430), 773–795.

Khan, A., R. King, and A. Wolman (2003). Optimal Monetary Policy. *Review of Economic Studies 70*(4), 825–860.

King, R., C. Plosser, and S. Rebelo (1988). Production, Growth and Business Cycles: The Basic Neoclassical Model. *Journal of Monetary Economics 21*(2-3), 195–232.

Kolasa, M. (2009). Structural Heterogeneity or Asymmetric Shocks? Poland and the Euro Area through the Lens of a Two-Country DSGE Model. *Economic Modelling 26*(6), 1245–1269.

Kollmann, R. (1995). Consumption, Real Exchange Rates and the Structure of International Asset Markets. *Journal of International Money and Finance 14*(2), 191–211.

Kollmann, R. (2001). The Exchange Rate in a Dynamic-Optimizing Business Cycle Model with Nominal Rigidities: a Quantitative Investigation. *Journal of International Economics 55*(2), 243–262.

Kollmann, R. (2002). Monetary Policy Rules in the Open Economy: Effects on Welfare and Business Cycles. *Journal of Monetary Economics 49*(5), 989–1015.

Kongsamut, P., S. Rebelo, and D. Xie (1997). Beyond Balanced Growth. Technical report, National Bureau of Economic Research.

Koop, G., M. H. Pesaran, and R. P. Smith (2011). On Identification of Bayesian DSGE Models. Unpublished Manuscript, University of Cambridge.

Kosova, R. (2010). Do Foreign Firms Crowd out Domestic Firms? Evidence from the Czech Republic. *The Review of Economics and Statistics 92*(4), 861–881.

Kydland, F. E. and E. C. Prescott (1980). Dynamic Optimal Taxation, Rational Expectations and Optimal Control. *Journal of Economic Dynamics and Control 2*, 79–91.

Lagarias, J., J. Reeds, M. Wright, and P. Wright (1998). Convergence Properties of the Nelder-Mead Simplex Method in Low Dimensions. *Journal of Optimization 9*, 112–147.

Lama, R. and J. Medina (2007). Optimal Monetary Policy in a Small Open Economy Under Segmented Asset Markets and Sticky Prices. *IMF Working Papers*.

Lane, P. and G. Milesi-Ferretti (2001). Long-Term Capital Movements. *NBER Macroeconomics Annual 16*, 73–116.

Lane, P. R. and G. M. Milesi-Ferretti (2007). The External Wealth of Nations Mark II: Revised and Extended Estimates of Foreign Assets and Liabilities, 1970–2004. *Journal of International Economics 73*(2), 223–250.

Laxton, D. and P. Pesenti (2003). Monetary Rules for Small, Open, Emerging Economies. *Journal of Monetary Economics 50*(5), 1109–1146.

Lein, S., M. León-Ledesma, and C. Nerlich (2008). How is Real Convergence Driving Nominal Convergence in the New EU Member States? *Journal of International Money and Finance 27*(2), 227–248.

Lein, S., M. Leon-Ledesma, and C. Nerlich (2009). The Link Between Real and Nominal Convergence: The Case of the New EU Member States. In R. Martin and A. Winkler (Eds.), *Real Convergence in Central, Eastern and South-Eastern Europe*, pp. 65–97. Palgrave Macmillan.

Leith, C., I. Moldovan, and R. Rossi (2012). Optimal Monetary Policy in a New Keynesian Model with Habits in Consumption. *Review of Economic Dynamics*.

Leith, C. and S. Wren-Lewis (2007). The Optimal Monetary Policy Response to Exchange Rate Misalignments. Unpublished Manuscript, Department of Economics, University of Oxford.

Levin, A. T., A. Onatski, J. Williams, and N. M. Williams (2006). Monetary Policy under Uncertainty in Micro-Founded Macroeconometric Models. In *NBER Macroeconomics Annual 2005, Volume 20*, pp. 229–312. MIT Press.

Lewis, J. (2009). Hitting and Hoping? Meeting the Exchange Rate and Inflation Criteria During a Period of Nominal Convergence. *European Journal of Political Economy 25*(4), 508–524.

Lin, J. (1991). Divergence Measures Based on the Shannon Entropy. *IEEE Transactions on Information Theory 37*(1), 145–151.

Lipinska, A. (2008). The Maastricht Convergence Criteria and Optimal Monetary Policy for the EMU Accession Countries. *ECB Working Paper No. 896*.

Lipsey, R. (2006). Measuring the Impacts of FDI in Central and Eastern Europe. Technical report, National Bureau of Economic Research.

Liu, Z. and E. Pappa (2008). Gains from International Monetary Policy Coordination: Does It Pay to Be Different? *Journal of Economic Dynamics and Control 32*(7), 2085–2117.

Lombardo, G. and F. Ravenna (2010). The Size of the Tradable and Non-Tradable Sector: Evidence from Input-Output Tables for 25 Countries. Unpublished Manuscript.

Lombardo, G. and D. Vestin (2008). Welfare Implications of Calvo vs. Rotemberg-Pricing Assumptions. *Economics Letters 100*(2), 275–279.

Lubik, T. and F. Schorfheide (2005). A Bayesian Look at the New Open Economy Macroeconomics. In *NBER Macroeconomics Annual 2005, Volume 20*, pp. 313–382. MIT Press.

Lubik, T. and F. Schorfheide (2007). Do Central Banks Respond to Exchange Rate Movements? A Structural Investigation. *Journal of Monetary Economics 54*(4), 1069–1087.

Lucas, R., N. Stokey, et al. (1983). Optimal Fiscal and Monetary Policy in an Economy without Capital. *Journal of Monetary Economics 12*(1), 55–93.

Luenberger, D. G. (2010). *Linear and Nonlinear Programming.* Springer.

MacDonald, R. and L. Ricci (2007). Real Exchange Rates, Imperfect Substitutability, and Imperfect Competition. *Journal of Macroeconomics 29*(4), 639–664.

Marinov, R. (2010). Competitive Pressure in Transition: A Role for Trade and Competition Policies? *Journal of Industry, Competition and Trade 10*(1), 1–31.

Maroto, A. and L. Rubalcaba (2008). Services Productivity Revisited. *The Service Industries Journal 28*(3), 337–353.

Martin, R. and A. Winkler (2009). *Real Convergence in Central, Eastern and South-Eastern Europe.* Palgrave Macmillan.

Masten, I. (2008). Optimal Monetary Policy with Balassa-Samuelson-Type Productivity Shocks. *Journal of Comparative Economics 36*(1), 120–141.

Mattesini, F. and S. Nisticò (2010). Trend Growth and Optimal Monetary Policy. *Journal of Macroeconomics 32*(3), 797–815.

McCallum, A. and F. Smets (2007). Real Wages and Monetary Policy Transmission in the Euro Area. Kiel Institute Working Paper.

Mendoza, E. (1991). Real Business Cycles in a Small Open Economy. *The American Economic Review 81*(4), 797–818.

Mihailov, A., F. Rumler, and J. Scharler (2011). Inflation Dynamics in the New EU Member States: How Relevant Are External Factors? *Review of International Economics 19*(1), 65–76.

Mihaljek, D. and M. Klau (2004). The Balassa–Samuelson Effect in Central Europe: A Disaggregated Analysis. *Comparative Economic Studies 46*(1), 63–94.

Mihaljek, D. and M. Klau (2008). Catching-Up and Inflation in Transition Economies: The Balassa-Samuelson Effect Revisited. *BIS Working Papers*.

Molnar, M. and N. Bottini (2008). How Large are Competitive Pressures in Services Markets? Estimation of Mark-Ups for Selected OECD Countries.

Monacelli, T. (2004). Into the Mussa Puzzle: Monetary Policy Regimes and the Real Exchange Rate in a Small Open Economy. *Journal of International Economics 62*(1), 191–217.

Monacelli, T. (2006). Monetary Policy in a Low Pass-Through Environment. *Journal of Money, Credit and Banking 37*(6), 1047–1066.

Mongelli, F., E. Dorrucci, and I. Agur (2005). What Does European Institutional Integration Tell Us about Trade Integration? *ECB Occasional Paper* (40).

Mundell, R. (1961). A Theory of Optimum Currency Areas. *The American Economic Review*, 657–665.

Nakamura, E. and D. Zerom (2010). Accounting for Incomplete Pass-Through. *The Review of Economic Studies 77*(3), 1192–1230.

Neumeyer, P. and F. Perri (2005). Business Cycles in Emerging Economies: the Role of Interest Rates. *Journal of Monetary Economics 52*(2), 345–380.

Ngai, L. and C. Pissarides (2007). Structural Change in a Multisector Model of Growth. *The American Economic Review 97*(1), 429–443.

North, D. (1990). *Institutions, Institutional Change, and Economic Performance*. Cambridge University Press.

Obstfeld, M. and K. Rogoff (1995). Exchange Rate Dynamics Redux. *Journal of Political Economy 103*(3).

Obstfeld, M. and K. Rogoff (2000). New Directions for Stochastic Open Economy Models. *Journal of International Economics 50*(1), 117–153.

Obstfeld, M. and K. Rogoff (2009). Global Imbalances and the Financial Crisis: Products of Common Causes. Centre for Economic Policy Research Discussion Paper No. DP7606.

OECD (2009). *OECD Economic Surveys: Austria-Volumes 2001,2003,2005,2007,2009*. Organisation for Economic Co-operation and Development.

Otrok, C. (2001). On Measuring the Welfare Cost of Business Cycles. *Journal of Monetary Economics 47*(1), 61–92.

Peersman, G. and R. Straub (2009). Technology Shocks and Robust Sign Restrictions in a Euro Area SVAR. *International Economic Review 50*(3), 727–750.

Pistor, K., M. Raiser, and S. Gelfer (2000). Law and Finance in Transition Economies. *Economics of Transition 8*(2), 325–368.

Rabanal, P. (2009). Inflation Differentials between Spain and the EMU: A DSGE Perspective. *Journal of Money, Credit and Banking 41*(6), 1141–1166.

Rabanal, P. and V. Tuesta (2010). Euro-Dollar Real Exchange Rate Dynamics in an Estimated Two-Country Model: An Assessment. *Journal of Economic Dynamics and Control 34*(4), 780–797.

Rabitsch, K. (2012). The Role of Financial Market Structure and the Trade Elasticity for Monetary Policy in Open Economies. *Journal of Money, Credit and Banking 44*(4), 603–629.

Ramsey, F. (1927). A Contribution to the Theory of Taxation. *The Economic Journal 37*(145), 47–61.

Ravenna, F. and F. Natalucci (2008). Monetary Policy Choices in Emerging Market Economies: The Case of High Productivity Growth. *Journal of Money, Credit and Banking 40*(2-3), 243–271.

Ravn, M. (2001). Consumption Dynamics and Real Exchange Rate. *CEPR Discussion Papers*.

Robert, C. (2007). *The Bayesian Choice: From Decision-Theoretic Foundations to Computational Implementation*. Springer.

Rotemberg, J. (1982). Monopolistic Price Adjustment and Aggregate Output. *The Review of Economic Studies 49*(4), 517–531.

Samuelson, P. (1964). Theoretical Notes on Trade Problems. *The Review of Economics and Statistics 46*(2), 145–154.

Scheines, R., H. Hoijtink, and A. Boomsma (1999). Bayesian Estimation and Testing of Structural Equation Models. *Psychometrika 64*(1), 37–52.

Schmitt-Grohé, S. and M. Uribe (2003). Closing Small Open Economy Models. *Journal of International Economics 61*(1), 163–185.

Schmitt-Grohe, S. and M. Uribe (2004). Optimal Fiscal and Monetary Policy under Sticky Prices. *Journal of Economic Theory 114*, 198–230.

Schmitt-Grohé, S. and M. Uribe (2004). Optimal Operational Monetary Policy in the Christiano-Eichenbaum-Evans Model of the US Business Cycle. Technical report, National Bureau of Economic Research.

Schmitt-Grohé, S. and M. Uribe (2005). Optimal Inflation Stabilization in a Medium-Scale Macroeconomic Model. Technical report, National Bureau of Economic Research.

Schmitt-Grohé, S. and M. Uribe (2006). Optimal Simple and Implementable Monetary and Fiscal Rules: Expanded Version.

Schorfheide, F. (2000). Loss Function-Based Evaluation of DSGE Models. *Journal of Applied Econometrics 15*(6), 645–670.

Selaive, J., V. Tuesta, and B. of Governors of the Federal Reserve System (US) (2003). *Net Foreign Assets and Imperfect Pass-Through: The Consumption Real Exchange Rate Anomaly*. Board of Governors of the Federal Reserve System.

Seoane, H. D. (2010). Policy Switches in Emerging Economies. Department of Economics, Duke University, Unpublished Manuscript.

Sims, C. (2002). Solving Linear Rational Expectations Models. *Computational Economics 20*(1), 1–20.

Smets, F. and R. Wouters (2002). Openness, Imperfect Exchange Rate Pass-Through and Monetary Policy. *Journal of Monetary Economics 49*(5), 947–981.

Smets, F. and R. Wouters (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association 1*(5), 1123–1175.

Smets, F. and R. Wouters (2005). Comparing Shocks and Frictions in US and Euro Area Business Cycles: a Bayesian DSGE Approach. *Journal of Applied Econometrics 20*(2), 161–183.

Smets, F. and R. Wouters (2007). Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review 97*(3), 586–606.

Söderström, U. (2010). Reevaluating Swedish Membership in the European Monetary Union: Evidence from an Estimated Model. In A. Alesina and F. Giavazzi (Eds.), *Europe and the Euro*, pp. 379–414. University of Chicago Press.

Solon, G., R. Barsky, and J. A. Parker (1994). Measuring the Cyclicality of Real Wages: How Important is Composition Bias. *Quarterly Journal of Economics 109*(1).

Stockman, A. and L. Tesar (1995). Tastes and Technology in a Two-Country Model of the Business Cycle: Explaining International Comovements. *The American Economic Review*.

Süppel, R. (2003). Comparing Economic Dynamics in the EU and CEE Accession Countries. *ECB Working Paper*.

Sutherland, A. (2002). International Monetary Policy Coordination and Financial Market Integration. Board of the Governors of the Federal Reserve System, International Finance Discussion Papers.

Sutherland, A. (2005). Incomplete Pass-Through and the Welfare Effects of Exchange Rate Variability. *Journal of International Economics 65*(2), 375–399.

Svejnar, J. (2002). Transition Economies: Performance and Challenges. *The Journal of Economic Perspectives 16*(1), 3–28.

Svensson, L. (2000). Open-Economy Inflation Targeting. Technical report, National Bureau of Economic Research.

Tavlas, G. (2007). The New Theory of Optimum Currency Areas. *The World Economy 16*(6), 663–685.

Uribe, M. (2011). Open Economy Macroeconomics. Manuscript, Columbia University.

Wagner, M. and J. Hlouskova (2005). CEEC Growth Projections: Certainly Necessary and Necessarily Uncertain. *Economics of Transition 13*(2), 341–372.

Walsh, C. E. (2003). Monetary Theory and Policy. *MIT Press Books*.

Wölfl, A. (2005). The Service Economy in OECD Countries. In *Enhancing the Performance of the Services Sector*. OECD.

Woodford, M. (2003). *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton University Press.