UNIVERSITY OF LJUBLJANA
SCHOOL OF ECONOMICS AND BUSINESS

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DYNAMIC STOCHASTIC GENERAL EQUILIBRIUM MODELS AND THEIR APPLICATIONS

DOCTORAL DISSERTATION

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AUTHORSHIP STATEMENT

The undersigned **Andrej Kuštrin**, a student at the University of Ljubljana, School of Economics and Business, (hereafter: SEB), author of this written final work of studies with the title **Dynamic stochastic general equilibrium models and their applications (Dinamični stohastični modeli splošnega ravnotežja in njihova uporaba)**, prepared under supervision of **prof. Igor Masten, Ph.D.**

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SUMMARY

The doctoral dissertation is comprised of three self-contained chapters on dynamic stochastic general equilibrium (DSGE) models and their applications. The first chapter entitled *Decomposing the Slovenian business cycle: Evidence from an estimated DSGE model* presents the estimation of a medium-scale DSGE model for the Slovenian economy. The model, which is built in the tradition of New Keynesian models, closely follows the structure of the models developed by Adolfson et al. (2007) and Masten (2010), where the latter author extends the framework of Adolfson et al. (2007) in two directions, namely, by (i) adapting the model to the small open economy case within the common currency area and (ii) enriching the fiscal block of the model. This chapter is itself a continuation of the work initiated in Masten (2010). Chapter is divided in three parts, among which the first part describes the structure of the model. Second part is focused on the estimation of the model, which is done by using a Bayesian method on quarterly Slovenian macroeconomic data covering the period 1995-2014. The last part deals with practical application of the model, role of various shocks in explaining macroeconomic fluctuations in the Slovenian economy, for the period 1995-2014, is discussed. Specifically, using historical decompositions, I estimate the individual contributions of each structural shock to the movements in real GDP growth and its main components over the sample period, with a particular focus on the most recent recessionary periods. I find the investment-specific technology shocks mostly accounted for a significant portion of drop in output growth from 2008 onwards. This result accords with a drop in foreign and domestic orders followed by a decline in investment (mostly at the beginning of the crisis) and the large amount of losses of the corporate sector that accumulated on balance sheets of the banks in the form of non-performing bad loans, further contributing to a contraction of lending activity which in turn reduced investment and impeded economic activity. Furthermore, the consumption preference and the export mark-up shocks were another sources that contributed negatively to GDP growth, reflecting the increase in households' precautionary saving and the fall in exports, respectively. The slowdown in GDP growth was also accompanied by permanent (unit-root) technology shocks that could be considered as associated with the lack of productivity-enhancing and other structural reforms in the run-up to the crisis. By contrast, transitory (stationary) technology shocks have positively contributed to GDP growth during the crisis, especially in the second recessionary period, which may be interpreted as resulting from a temporary greater tendency of corporate sector to take restructuring measures in response to the crisis to improve its competitive position. Finally, the results show that the recovery phase after 2013 is explained mainly by consumption preference shocks, which could be explained by the increased consumer confidence, resolution of banking system problems as well as by the improvement in the labour market situation.

The second chapter with the title *Evaluating fiscal rules in an estimated DSGE model* considers the estimated DSGE model from the first chapter to assess the performance of alternative forms of fiscal rules. In particular, comparisons focus on five fiscal rules, namely the optimal simple rule for government consumption (OSR), the balanced budget rule (BBR), the structural budget rule (SBR), the basic debt brake rule (DBR) and the optimal debt brake rule (OptDBR). The results are described in two parts. In the first part, I compare the volatility changes in key macroeconomic variables by showing their respective standard deviations for each of these rules. Then, I evaluate the performance of the rules against the welfare criterion: a fiscal authority loss function containing the deviations of inflation and output gap from their equilibrium values. In

the second part, I perform a counter-factual exercise, which allows me to investigate how different the evolution of the Slovenian macroeconomic variables would have been between 1995 and 2014, if the above-mentioned fiscal rules had been in place. The first finding is that all types of fiscal rules increase government expenditure stability and the welfare compared to of what it would be if a fiscal authority committed itself to the BBR. Specifically, the OSR is the best welfare performer within the set I consider. The second best performance belongs to the OptDBR, while the third best performance occurs when the government follows the DBR. Concerning the public debt stabilization, the following results emerge: the OSR and DBR give quite similar results regarding the public debt volatility. Further, comparing the public debt volatility under the DBR and OptDBR, one can observe that while the latter is more successful in reducing the volatility of GDP growth movements, it gives higher volatility of public debt relative to the volatility implied by the DBR, indicating that there exists a trade-off between these two objectives. Finally, the lowest volatility of public debt is achieved under the BBR and SBR, where both rules generate quite comparable results. Last, the results based on historical counter-factual simulations show that Slovenia would have experienced more sustainable public debt path compared to the actual one, if a fiscal rule had been used since 1995. This finding is consistent with previous findings in the literature (see, for example, Andrle et al., 2015). Public debt at lower levels would have several positive macroeconomic consequences, including decreasing interest rates, capital inflow, optimistic expectations, increase in economic activity and subsequent improvement in public finances.

The third chapter titled *Electricity in a DSGE Model Setting*, joint work with prof. Igor Masten, extends the DSGE model of Adolfson et al. (2007) and Masten (2010) by incorporating electricity price shocks into it in order to make it suitable for carrying out electricity sector related analyses for the Slovenian economy. The model was developed as part of a research project (carried out during the doctoral study) for practical uses at a company operating in the electricity sector. The key feature of this new model is that it explicitly includes electricity in the consumption basket and also in the production technology used by domestic firms and allows the prediction of changes in the electricity price components, such as market price of electricity, price for the use of the network, contributions and the excise duties on electricity, on key macroeconomic variables, including public finance. It is also possible to utilize the model to quantify the impact of electricity price changes on household and industrial electric energy consumption. The model is partly estimated (general parameters) and partly calibrated (electricity related parameters) at a quarterly frequency. Using impulse response analysis, we illustrate the usefulness of the model in quantifying the reaction of key macroeconomic variables in the model on price changes in the electricity price components. Overall, we find our proposed model well suited for performing electricity sector related analyses.

Key words: Bayesian method, Historical decomposition, Fiscal rules, Electricity price components, DSGE

POVZETEK

Doktorska disertacija vsebuje tri poglavja o dinamičnih stohastičnih modelih splošnega ravnotežja (DSGE) in njihovi praktični uporabi. V prvem poglavju z naslovom *Dekompozicija slovenskega poslovnega cikla: rezultati ocenjenega DSGE modela* je predstavljen ocenjen DSGE model za Slovenijo, ki služi kot osnovno metodološko orodje skozi celotno doktorsko disertacijo. Model, ki gradi na temeljih Novo Keynesianske ekonomike, je osnovan na modelih iz člankov Adolfson et al. (2007) in Masten (2010). Slednji je model iz Adolfson et al. (2007) dopolnil v dveh smereh, in sicer: (i) s prilagoditvijo modela za majhno odprto gospodarstvo znotraj skupnega denarnega območja in (ii) z razširitvijo modela v njegoven fiskalnem delu. V prvem poglavju doktorske disertacije, ki predstavlja nadaljevanje dela, začetega v Masten (2010), sem najprej ocenil strukturne parametre in šoke omenjenega modela, in sicer z Bayesiansko statistično metodo na podlagi četrtletnih podatkov za Slovenijo za obdobje 1995-2014. Nato sem prikazal uporabo modela na primeru strukturne analize poslovnega cikla. V ta namen sem naredil historično dekompozicijo gibanja realne rasti slovenskega BDP-ja (in njegovih komponent) v obdobju 1995-2014, s posebnim poudarkom na nedavnih obdobjih recesije. Rezultati kažejo, da so v obdobju prve recesije (2008-2009) pomemben dejavnik negativne gospodarske rasti predstavljali investicijski šoki, ki so se odražali v padcu investicij kot posledica zmanjšanja tujih in domačih naročil kot tudi povečane negotovosti glede prihodnjih ekonomskih obetov. V nekoliko manjši meri so imeli negativen vpliv na gospodarsko rast potrošno-preferenčni šoki in šoki v pribitkih izvoznega sektorja, kar lahko v prvem primeru povezujem s padcem dohodkov gospodinjstev (v povezavi s povečanim previdnostnim varčevanjem), v drugem primeru pa s padcem izvoznega povpraševanja zaradi poslabšanja konkurenčnosti domačega gospodarstva, ki je nastala zaradi hitrejše rasti plač od rasti produktivnosti v predkriznem obdobju. Poleg tega so na gospodarsko rast negativno vplivali tudi permanentni tehnološki šoki, ki jih lahko povezujem predvsem z odsotnostjo ustreznih strukturnih reform v času pred začetkom krize. Po drugi strani pa so imeli stacionarni tehnološki šoki pozitiven vpliv na gospodarsko rast, posebej v času druge recesije, kar lahko odraža težnjo podjetij po sprejemanju ukrepov za izboljšanje svojega konkurenčnega položaja. Nazadnje rezultati kažejo, da je okrevanje gospodarske aktivnosti na koncu proučevanega obdobja izhajalo predvsem iz pozitivnega vpliva potrošno-preferenčnih šokov, ki jih lahko povezujem z večjim zaupanjem potrošnikov, izvedeno sanacijo bančnega sistema in izboljšanjem razmer na trgu dela.

V drugem poglavju, ki nosi naslov *Ovrednotenje fiskalnih pravil v ocenjenem DSGE modelu*, je prikazana možnost uporabe DSGE modela iz prvega poglavja na področju fiskalne politike. V ta namen sem primerjal makroekonomske učinke petih različnih fiskalnih pravil. Prvo fiskalno pravilo je pravilo uravnoteženega proračuna (angl. *balanced budget rule - BBR*), ki v vsakem obdobju izenačuje državne izdatke s prihodki proračuna. Drugo fiskalno pravilo, ki ga analiziram, je optimalno enostavno fiskalno pravilo (angl. *optimal simple fiscal rule – OSR*), ki povezuje državno potrošnjo z gibanjem ključnih makroekonomskih agregatov (inflacije, proizvodne vrzeli, proračunskega salda in javnega dolga). Koeficiente odziva sem določil na podlagi minimizacije funkcije izgube, ki je sestavljena iz dveh členov: variance inflacije in variance proizvodne vrzeli. Za razliko od centralne banke predpostavljam, da fiskalna oblast namenja večjo pozornost stabilizaciji proizvodnje vrzeli, zato le-ta vstopa v funkcijo izgube z relativno višjo utežjo. Omenjena funkcija izgube obenem služi kot za medsebojno primerjavo obravnavanih fiskalnih pravil. Tretje proučevano fiskalno pravilo je pravilo strukturnega salda (angl. *structural budget rule – SBR*). Kot četrto fiskalno pravilo analiziram pravilo dolžniške zavore (angl. *debt brake rule – DBR*). Značilnost tega pravila je, da določa najvišjo dovoljeno mejo državnih izdatkov na podlagi trendnih prihodkov. Zadnje analizirano fiskalno pravilo pa je pravilo optimalno pravilo dolžniške zavore (angl. *optimal debt brake rule – OptDBR*), na podlagi katerega se državni izdatki avtomatično odzivajo na gibanje proizvodne vrzeli, pri čemer je koeficient odziva tudi v tem primeru določen tako, da je funkcija izgube minimizirana. Skladno s pričakovanji rezultati simulacij kažejo, da vsa proučevana fiskalna pravila omogočajo doseganje višje stopnje blaginje v primerjavi z BBR. Najvišja stopnja blaginje je dosežena pod OSR, sledi OptDBR, na tretjem mestu je DBR, medtem ko predzadnje mesto zaseda SBR. Glede stabilizacije javnega dolga so rezultati naslednji: OSR in DBR dajeta enakovredne rezultate glede stabilizacije javnega dolga. Nadalje primerjava med DBR in OptDBR kaže, da slednje sicer vodi do nižje volatilnosti gospodarske rasti, a obenem povzroča višjo volatilnost javnega dolga, kar nakazuje na izključevanje teh dveh ciljev. Najnižja volatilnost javnega dolga je dosežena pod BBR in SBR, pri čemer obe pravili dajeta podobne rezultate. Nazadnje sem izvedel še protidejstveni eksperiment (angl. *counter-factual experiment*), s katerim sem poskušal odgovoriti na vprašanje, kakšno bi bilo gibanje rasti BDP-ja, rasti državne potrošnje, proračunskega salda in javnega dolga v Sloveniji med letoma 1995 in 2014, če bi bila v veljavi proučevana fiskalna pravila. Rezultati analize kažejo, da bi Slovenija dosegala bistveno bolj vzdržno gibanje javnega dolga, kar bi imelo številne pozitivne makroekonomske posledice, kot so nižje obrestne mere, pritok kapitala, optimistična pričakovanja, povečanje ekonomske aktivnosti in nadaljnje izboljšanje javnih financ.

V okviru tretjega poglavja doktorske disertacije z naslovom *Elektrika v DSGE modelu*, ki je nastalo v soavtorstvu s prof. Igorjem Mastenom, so raziskovalne aktivnosti usmerjene v izgradnjo DSGE modela, ki naj bi služil kot orodje za analizo makroekonomskih učinkov sprememb cen posameznih komponent električne energije na slovensko gospodarstvo. Model je bil razvit v okviru projektne naloge (izvedene tekom doktorskega študija) za praktično uporabo v elektroenergetskem podjetju, s čimer je bila prisluhnjena konkretna potreba gospodarstva. V ta namen je bil DSGE model iz prvega poglavja doktorske disertacije dopolnjen s šoki v cenah električne energije. Značilnost novo razvitega modela je, da eksplicitno vključuje električno energijo v potrošni košarici gospodinjstev kot tudi v proizvodni tehnologiji podjetij, kar je zahtevalo vrsto dopolnitev osnovnega modela, predstavljenega v prvem poglavju doktorske disertacije. Model omogoča simulacijo makroekonomskih učinkov sprememb posameznih komponent cene električne energije - grosistične cene, nadomestil za uporabo omrežja in prispevkov, ki jih določata Vlada RS in Agencija za energijo, ter trošarin, kot tudi simulacijo vpliva sprememb cen na prihodke državnega proračuna in na gospodinjski ter poslovni odjem elektrike. Vrednosti splošnih parametrov so postavljene tako, da so delno uporabljene ocenjene vrednosti iz prvega poglavja doktorske disertacije, delno pa iz različnih (mikroekonomskih) študij, medtem ko so parametri, povezani z električno energijo, kalibrirali na podlagi podatkov za slovenski trg električne energije. V zadnjem delu poglavja je prikazana možnost uporabe modela v praksi na primeru nekaj hipotetičnih scenarijev.

Ključne besede: Bayesianska metoda, Historična dekompozicija, Fiskalna pravila, Komponente cene električne energije, DSGE

TABLE OF CONTENTS

INTRODUCTION **1**

1 DECOMPOSING THE SLOVENIAN BUSINESS CYCLE: EVIDENCE FROM AN ESTIMATED DSGE MODEL[1] **8**

1.1 Introduction 8
1.2 The model 11
1.2.1 Supply side of the economy 11
1.2.1.1 Domestic firms 11
1.2.1.2 Importing and exporting firms 12
1.2.2 Demand side of the economy 13
1.2.2.1 Households 13
1.2.3 Monetary policy 15
1.2.4 Fiscal policy 16
1.2.5 Market equilibrium 17
1.2.6 Foreign economy 17
1.2.7 Structural shocks 18
1.3 Model solution and estimation 18
1.3.1 Model solution 18
1.3.2 Data and measurement equations 19
1.3.3 Estimation methodology 21
1.3.4 Calibrated parameters 23
1.3.5 Prior distributions of the estimated parameters 24
1.4 Estimation results and evaluation 26
1.4.1 Posterior distributions of the estimated parameters 26
1.4.2 Assessing the empirical performance of the model 32
1.5 Application: What structural shocks drive the Slovenian economy? 33
1.5.1 Impulse response analysis 33
1.5.2 Variance decompositions 35
1.5.3 Historical decompositions 37
1.6 Conclusions and policy recommendations 40

2 EVALUATING FISCAL RULES IN AN ESTIMATED DSGE MODEL **42**

2.1 Introduction 42
2.2 A brief overview of the E(M)U fiscal framework 45
2.3 Model and parameters 48
2.3.1 Model overview 48
2.3.2 Parametrization 50
2.4 Evaluating fiscal policy rules 50
2.4.1 Specification of fiscal rules 51
2.4.1.1 The optimal simple fiscal rule 51
2.4.1.2 The balanced budget rule 53

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2.4.1.3 The structural balance rule 54
2.4.1.4 The basic debt brake rule 55
2.4.1.5 The optimal debt brake rule 57
2.4.2 Simulation results and discussion 58
2.4.2.1 Impulse-response analysis 58
2.4.2.2 Macroeconomic volatility and welfare comparison 59
2.4.2.3 Historical counter-factual analysis 63
2.5 Conclusions and policy recommendations 66

3 ELECTRICITY IN A DSGE MODEL SETTING[2] 69
3.1 Introduction 69
3.2 The DSGE model 70
3.2.1 Aggregate supply 70
3.2.2 Aggregate demand 71
3.2.3 Foreign sector 73
3.2.4 Public sector 73
3.2.5 Market equilibrium 73
3.3 Calibration and estimation 74
3.3.1 Calibration of electricity sector related parameters 74
3.3.2 Modelling electricity price shocks 77
3.4 Simulation properties of the model 79
3.5 Conclusion 86

CONCLUSION 87

REFERENCE LIST 91

APPENDICES 99

A Steady state of the baseline model specification 1

B Derivation of the wage-setting equation 6

C Fiscal block of the model 14

D Complete model in log-linearized form (the baseline model specification) 24

E Data sources and description 31

F Measurement equations 31

G Prior and posterior distributions 42

H Diagnostic plots 47

I Data and one-sided predicted values from the model 69

[2]This chapter is joint work with Igor Masten.

J Smoothed shocks **70**

K Impulse response functions **72**

L Historical decompositions **77**

M Fiscal rules simulation procedure details **81**

N Steady state of the model specification with electricity price shocks **82**

O Complete model in log-linearized form (the model specification with electricity price shocks) **88**

P Graphical user interface for the model with electricity **91**

Q Description of variables used in the model (the baseline model specification & the model specification with electricity price shocks) **93**

R Summary in Slovenian language/Daljši povzetek v slovenskem jeziku **97**

LIST OF FIGURES

1 Historical decomposition of GDP growth in terms of the structural shocks . . . 40
2 Impulse response functions to a negative investment shock under alternative fiscal rules . . . 60
3 Historical (smoothed) and simulated time series of some key variables under alternative fiscal rules . . . 66
4 Historical electricity prices for household consumers (PE), consumer price index (CPI) and producer price index (PPI) . . . 76
5 Historical relative electricity prices for household consumers . . . 77
6 Impulse responses to a 1 % permanent increase in wholesale electricity prices - effects on main macroeconomic aggregates . . . 81
7 Impulse responses to a 1 % permanent increase in wholesale electricity prices - effects on state budget . . . 82
8 Impulse responses to a 1 % permanent increase in wholesale electricity prices - effects on inflation and electricity consumption . . . 83
9 Impulse responses to a 1 % permanent increase in electricity prices for industrial consumers - effects on main macroeconomic aggregates and electricity consumption . . . 84
10 Impulse responses to a 1 % permanent increase in electricity prices for household consumers - effects on main macroeconomic aggregates and electricity consumption . . . 85
11 Impulse responses to a 4 % permanent increase (within a one-year horizon) in electricity prices - effects on main macroeconomic aggregates and electricity consumption . . . 86

LIST OF TABLES

1	Calibrated parameters of the model	24
2	Steady state relationships	25
3	Prior and posterior distribution of structural parameters	29
4	Prior and posterior distribution of shock processes	30
5	Unconditional second moments in the data (1995Q2-2014Q4) and in the model	33
6	Variance decompositions (in %) evaluated at the infinite horizon	37
7	Optimized feedback coefficients in the simple fiscal rule	53
8	Macroeconomic volatility around the steady state (measured as standard deviation) of some key variables under alternative fiscal rules	62
9	Unconditional losses under alternative fiscal rules ($\lambda_\pi = 0.2$ and $\lambda_y = 1$)	62
10	Possible exogenous changes to the electricity price components	79
11	Shares of different components in the final electricity price	79
Q.1	Description of variables used in the model	93

LIST OF APPENDICES

Appendix A: Steady state of the baseline model specification 1
Appendix B: Derivation of the wage-setting equation 6
Appendix C: Fiscal block of the model 14
Appendix D: Complete model in log-linearized form (the baseline model specification) 24
Appendix E: Data sources and description 31
Appendix F: Measurement equations 31
Appendix G: Prior and posterior distributions 42
Appendix H: Diagnostic plots 47
Appendix I: Data and one-sided predicted values from the model 69
Appendix J: Smoothed shocks 70
Appendix K: Impulse response functions 72
Appendix L: Historical decompositions 77
Appendix M: Fiscal rules simulation procedure details 81
Appendix N: Steady state of the model specification with electricity price shocks 82
Appendix O: Complete model in log-linearized form (the model specification with electricity price shocks) 88
Appendix P: Graphical user interface for the model with electricity 91
Appendix Q: Description of variables used in the model (the baseline model specification & the model specification with electricity price shocks) 93
Appendix R: Summary in Slovenian language/Daljši povzetek v slovenskem jeziku 97

INTRODUCTION

Description of the dissertation topic area

New-Keynesian dynamic stochastic general equilibrium (DSGE) models have become a standard tools for macroeconomic analysis. They are widely used at many institutions, such as the European Central Bank (ECB), International Monetary Fund (IMF) and others. The key feature of these models is that they are derived from the microeconomic foundations meaning that they assume optimizing agents which usually form rational expectations and maximize their objective functions subject to their respective constraints in the presence of imperfect competition and different rigidities (Slanicay, 2015). **A general topic of this dissertation** is the estimation of a medium-scale DSGE model for the Slovenian economy and presentation of three fields of applications of this model.

Dynamic general equilibrium theory was founded in the early 1970s when economists started developing prototype models of rational expectations (see e.g. seminal papers by Lucas & Prescott, 1971; Lucas 1972), which can be considered as the predecessors of DSGE models. The aim was to develop the model which would be immune to the Lucas critics, i.e. a model containing parameters which could be considered independent of the economic policy. The first DSGE model was formed by Kydland and Prescott (1982) who presented a small dynamic model of the economy referred to as real business cycle model (RBC) comprised of optimizing agents, rational expectations, and market clearing. Despite their success in replicating a number of stylized facts of the business cycle, they were criticized on various aspects. In particular, there are at least three major critics that have to be addressed (Mankiw, 1989): the first critics were appalled to whole idea that technological shocks could account for a substantial fraction of business cycle fluctuations. The second critics was regarding the assumption of perfectly flexible prices. The third critics was related with the little role these models give to monetary policy. Indeed, they were unable to replicate empirical evidence of non-neutrality of money (see Christiano et al., 2005). As a response to these critics, the evolution of the so-called New Keynesian models began. These models shares the methodology and the underlying structure of RBS models. However, they have been augmented with some Keynesian assumptions such as nominal variables, imperfect competition and nominal rigidities. As time went by, a large body of work developing and strengthening DSGE models has evolved. The most influential papers in these area include Clarida et al. (1999, 2001), Beningo & Beningo (2003), Galí & Monacelli (2005), Christiano et al. (2005), Smets & Wouters (2003, 2007), Adolfson et al. (2007) and many others.

There is a vast scope of applications of these models. This dissertation presents three of them which are split into three self-contained chapters, briefly summarized below. The first chapter titled *Decomposing the Slovenian business cycle: Evidence from an estimated DSGE model* estimates a medium-scale DSGE model for the Slovenian economy, which is used to investigate the causes of the Slovenian recessions and, more broadly, the drivers of the Slovenian business cycle. Since its independence, Slovenia's GDP grew on average 4.5 % per year. The highest growth rate of GDP was achieved in the years 2006-2008 reached its peak in 2007, when it was 6.7 %. When the financial crisis hit the global economy, Slovenia has been affected by more than other countries. In 2009, GDP fell by 7.9 %. Later on, especially in 2010 a relative recovery began, but however in 2012 Slovenia entered a double dip recession. The economic deterioration in Slovenia's most important EU trading partners and the need of fiscal consolidation were obviously two main reasons why Slovenia remained in recession in 2012 and recovered only slowly thereafter. Another important reason for the slower recovery was the credit crunch. Prior to the crisis, Slovenia experienced large inflows of cheap credit from abroad mainly directed towards to construction companies and management buyouts/corporate takeovers. At the onset of the crisis the inflow of cheap credit suddenly stopped and the crisis in the construction and real estate market emerged. As a result, the Slovenian banks accumulated a large amount of non-performing bad loans, resulting in a credit crunch which in turn caused a cutback in corporate investment and impeded economic activity. In the beginning of 2014, the economic recovery finally started, thanks to the stronger international environment and the series of structural reforms implemented, including the resolution of banking system problems. In order to empirically classify the relative importance of these events in explaining the business cycle fluctuations in Slovenia in recent years, I calculate the variance and historical decompositions in terms of model structural shocks. It is important for policy makers to understand what role different shocks play in business cycle in order to assess the potential success of past policy measures adopted. At the same time, the results can also serve as a basis for formulating future economic policy actions. To the best of my knowledge, this is the first attempt to estimate a medium-scale DSGE model for Slovenia with an application to the business cycle analysis.

The second chapter with title *Evaluating fiscal rules in an estimated DSGE model* uses the estimated DSGE model with a detailed description of the fiscal policy block to assess the performance of different types of fiscal rules. In the most recent recession, due to the excessive spending during good times and fast growing debts and deficits in the time of crisis, governments in many countries had no available fiscal space to mitigating the recession. Adopting fiscal rule is one of the way that can help to prevent such situations in the future. Recently, the use of fiscal rules has been promoted by many international institutions such as the European Commission, IMF and OECD (IMF, 2009; OECD, 2012). In a broad sense, fiscal rules can be understand as a set of rules and regulations according to which budgets are drafted, approved and implemented (Alessina, 1999). For the purpose of this chapter the narrower definition by Kopits & Symansky (1998) is used: a fiscal rule is defined as a (statutory or constitutional) restriction on fiscal policy that sets a specific limit on a selected fiscal indicator. In practice, countries adopted fiscal rules for a wide variety of reasons.[3] Some countries adopted fiscal rules in order to ensure macroeconomic stability. Other countries wanted to enhance credibility of the government's fiscal policy. There are also countries that introduced fiscal rules with the aim to ensure long-term sustainability of public finances. The design of fiscal rules is a process that needs to take into account several aspects and comes along with several challenges. Besides the choice of an appropriate rule, there are also other features which are crucial for the effective implementation of rules. These include monitoring and enforcement schemes, type of legislative support and quality of public financial management system (IMF, 2018).[4] In this dissertation, instead of focusing on these theoretical issues, I simulate the DSGE model to examine the properties of five different types of fiscal rules in terms of their ability to contribute to macroeconomic stabilization and welfare.

[3] For a broader discussion of factors influencing the adoption of fiscal rules, see Altunbaş & Thornton (2017).
[4] See also IMF (2009) for a description of these features.

And the third chapter titled *Electricity in a DSGE Model Setting*, which is a joint work with prof. Igor Masten, sets up a DSGE model with electricity price shocks as a tool for carrying out electricity sector related analyses for the Slovenian economy. Electricity is considered as one of the most important forms of energy. It is used in a wide variety of fields that affect our lives. Because of its important role in the functioning of the economy and the life of the population, the change of its price raises questions about macroeconomic and microeconomic effects. In order to ensure efficient electricity power transmission through the transmission network, it is also of particular importance for electricity generating firms to know the economic effects of the price changes of different components that make up the end electricity price. The effects of energy prices on macroeconomic activity have always been an area for research for the economists, but the literature for a particular case of electricity prices is scarce since the literature typically focuses on oil price shocks (see, for example, Kilian, 2008, 2009; Peersmann & Van Robays, 2009; Medina & Soto, 2005; among many others). The third chapter attempts to fill this gap by presenting a new model framework that enables an analysis of the effects of electricity price changes on macroeconomic variables. Such a framework seems particularly appropriate for companies operating in the electricity sector. It is crucial for these companies to know the impact of possible changes in electricity prices on main economic indicators (e.g., the GDP, electricity demand and others) since these affect management decisions in a number of areas, including transmission network planning, revenue calculations and many others (Rhys, 1984). This necessitates the use of macroeconomic models that can be useful for the support of decision making.

In what follows, I first explain research purposes, objectives and contributions of the dissertation. Next, I briefly describe research methods and data. And finally, I present structure and contents of the dissertation. In the remainder of the dissertation, each of the three chapters is presented.

Research purposes, objectives and contributions of the dissertation

This chapter presents research purposes, objectives and contributions of the dissertation for each chapter.

Decomposing the Slovenian business cycle: Evidence from an estimated DSGE model. **The purpose of the first chapter** is to empirically evaluate sources of business cycle fluctuations in Slovenia. For this purpose, I use a small open economy DSGE model in line with Adolfson et al. (2007) and Masten (2010). The estimates of the model, which are obtained using a Bayesian estimation techniques, are further utilized to parametrize the model in order to explore the relative importance of different shocks in explaining fluctuations of macroeconomic variables in Slovenia. Specifically, I perform a historical decomposition of the dynamics of real GDP growth rate and its main components in order to analyse what role different shocks have played in the dynamics of these variables over the sample period, particularly since the onset of the crisis. In addition, the estimated DSGE model also serves as the main methodological tool in the second and third chapter of the dissertation. **This chapter addresses the following research questions**: *(1) What are the estimates of structural parameters and shocks for the Slovenian economy?; (2) What are the driving forces of the real business cycle in Slovenia?; (3)*

What are the similarities and differences between the 2008-2009 and 2012-2013 recession in terms of structural shocks?; (4) What structural shocks are the most important contributors to the recovery of economic activity after 2013? **The contribution of this chapter is threefold.** First, from the methodological point of view, it applies the Bayesian estimation method to the estimation of a DSGE model for the Slovenian economy, and therefore, presents evidence for additional country on the estimates of the structural (deep) parameters. To the best of my knowledge, this is the first attempt to estimate a medium-scale DSGE model for Slovenia. Second, from the empirical point of view, this chapter contributes to the knowledge by identifying the shocks that were responsible for the recent recession and the key sources of macroeconomic fluctuations in Slovenia in order to illustrate the model's potential in structural business cycle analysis. In this context, the chapter also provides some policy recommendations for economic policies. Third, giving a detailed description of DSGE modelling and illustrating the application of the model to the analysis of the business cycle fluctuations, the chapter also has important practical contributions for the Slovenian policy institutions, which may be interested in using the model presented here to support their policy processes.

Evaluating fiscal rules in an estimated DSGE model. **The purpose of the second chapter** is to employ the estimated DSGE model from the first chapter to analyse the macroeconomic volatility implications and relative welfare ranking of five alternative fiscal rules for a small open economy in the case of Slovenia. Namely, the comparison focuses on the optimal simple rule for government consumption (OSR), the balanced budget rule (BBR), the structural budget rule (SBR), the basic debt brake rule (DBR) and the optimal debt brake rule (OptDBR). Some of these rules are more theoretical while others are indeed implemented in practice. The main motivation behind this research is on the one hand, the growing interest in rule-based fiscal policies and on the other relatively small number of works that welfare rank alternative fiscal rules in a DSGE framework. **The research questions addressed are as follows.** *(1) How much stabilization is provided by different types of fiscal rules?; (2) Which fiscal rule is better from a welfare point of view?; (3) How would the selected macroeconomic variables in Slovenia have evolved if the government had been following fiscal rules presented in this chapter?* **The main contribution of this chapter** is a comprehensive analysis of five different types of fiscal rules. To the best of my knowledge, such set of fiscal rules, has not yet been used in this strand of economic modelling. Specifically, the rules are analysed in three different ways. First, I investigate the comparative properties of the five fiscal rules considered by studying impulse-responses of key macroeconomic variables to a negative investment shock. The motivation for considering this exercise is that the estimation results and historical decomposition analysis from the first chapter show that investment shocks accounted for a large share of output growth fluctuations in Slovenian economy during the last recessions. Second, I study the implications of the different fiscal rules for macroeconomic volatility and compare which of these rules is better from a welfare perspective. Finally, I conduct a counter-factual historical exercise, which consists of contrasting actual paths of selected macroeconomic variables in Slovenia during the 1995-2014 period with the values that would have been implied by each of the five fiscal rules respectively. Based on the results obtained, the chapter also draws some policy recommendations for the conduct of fiscal policy.

Electricity in a DSGE Model Setting. **The purpose of the third chapter** is to develop a DSGE model with electricity. In addition, the chapter presents the simulation properties of the model using some hypothetical scenarios. The structure of the model builds largely on the previous work by Adolfson et al. (2007) and Masten (2010) with one notable difference - we include electricity in the consumption basket and also in the production technology used by domestic firms. The parameters of the model are partly estimated by Bayesian methods on quarterly Slovenian macroeconomic data over the period 1995-2014. The remaining parameters, which mostly pertain to the electricity block of the model are calibrated using the data on Slovenian electricity market.[5] The properties of the model are illustrated with the response of key economic indicators, to changes in electricity price components such as the price of energy, the price for the use of the network, the contributions and the excise duties on electricity. The simulations presented are designed to illustrate how the model might be applied in a realistic practice scenario and how price changes of different components underlying the final electricity price translates into macroeconomic behaviour. **The main research question in this chapter is:** *(1) What are the effects of electricity price shocks on the Slovenian economy?* **The contribution of this chapter is on methodological, empirical and practical ground.** From a methodological point of view, this chapter develops an analytical framework based on a DSGE model that is suitable for carrying out electricity sector related analyses. This is to the best of our knowledge the first attempt to incorporate electricity in a DSGE model that reflects specific features of the Slovenian electricity market. Empirical contribution arises from the assessment of the effects of electricity price changes on the Slovenian economy. And lastly, practical contribution of this chapter is that it sets up the model that could be used for practical purposes inside companies operating in the electricity sector. Our study thus responds to the call made by one of these companies for the development and calibration of the model for Slovenia in order to enable company's staff to perform electricity sector related scenarios on their own after having received appropriate training.

Research objectives are derived from the research purposes and refer to the steps needed to achieve the aims. The main research objective of this dissertation is to employ a medium-scale DSGE model borrowed from Adolfson et al. (2007) and Masten (2010) and estimate it with quarterly Slovenian data. But before the estimation can begin, it is necessary to implement the model in Dynare, which is also an objective required to meet the research purpose. Related to the main research objective, additional research objectives are as follows. For the purposes of the second chapter, the baseline model is augmented with several fiscal features, among the most important being the introduction of fiscal rules. In the third chapter, the model structure and the steady state is adapted with electricity price elements. Another objective in the third chapter is to collect the data needed for the calibration of electricity sector related parameters. This is a crucial step towards making the model useful in performing reliable simulations.

Research methods and data

As it is indicated in the title, this chapter briefly presents **research methods** and **data** used in the dissertation. The analysis in the dissertation relies on a dynamic stochastic general equilibrium (DSGE) model, which has recently become widely used tool in terms of policy analysis. As its

[5]The key features of the Slovenian electricity marked are described in great detail in Annual Reports on the energy sector in Slovenia (view the web page of the Energy Agency of the Republic of Slovenia).

name indicates, this model is: *(D) dynamic*, which means that it takes into account that economic conditions and agents decisions change over time; *(S) stochastic*, which means that it allows random fluctuations in the economy as a consequence of different shocks; and it forms *(GE) general equilibrium*, which means that it takes into account optimal microeconomic decisions of different agents and connects partial equilibriums into general equilibrium.

Specifically, this dissertation uses a medium-scale small open-economy New Keynesian DSGE model similar to Adolfson et al. (2007) and Masten (2010). Masten (2010) further extended the model of Adolfson et al. (2007) in two directions, namely by: (i) adapting the model for a small-open economy in monetary union and (ii) augmenting fiscal block of the model. The development of the model (called SLODSGE 1.0) started in the year 2008 within the framework of a cooperation between the Slovenian Ministry of Finance, the Institute of Macroeconomic Analysis and Development and the Slovenian Research Agency. The model was primarily designed to be used as a tool for guiding economic policy-making in Slovenia. During the doctoral study, the previously developed model was maintained and further developed. In what follows, I briefly summarize the main features of the model. The model economy consists of a small open economy and the rest of the world and contains households, firms (which are of three types: domestic, importing and exporting), a monetary authority and a passive fiscal authority. Households derive utility from consumption and labour supply, given inter-temporal budget constraint. The model incorporates both nominal (sticky prices and wages) and real rigidities in preferences and production (habit formation in consumption, investment adjustment costs, and variable capital utilization). Prices and wages are set according to a Calvo (1983) mechanism, augmented by indexation to the previous period's inflation for those firms not allowed to re-optimize their pricing decision. The behaviour of the central bank is described by a simple monetary rule, which relates the policy rate (i.e. the short-term nominal interest rate) to the lagged policy rate, inflation, output gap and changes in inflation and output gap. The fiscal block of the model is represented by the usual government budget constraint. On the revenue side, the government raises revenue by collecting taxes on consumption, labour and capital. In addition, it can raise revenue by issuing new debt. On the expenditure side, the government pays for its direct purchases of goods and services, provides social transfers to households and services the debt by paying the interest charges. The fiscal side of the model is closed by specifying how fiscal policy is conducted. Fiscal policy refers to government spending for which it is assumed that follows a simple AR(1) process.

The model is fitted to quarterly Slovenian data for the sample period 1995-2014 through a combination of calibration and Bayesian estimation. Briefly, the key idea of the Bayesian estimation method, which is widely used in the estimation of DSGE models, is that it combines prior beliefs about the parameters with likelihood information contained in the data to form the posterior distributions of the parameters. Before the estimation can begin, prior beliefs need to be quantified into probability (prior) distributions. In the choice of priors, I mainly follow the papers of Adolfson et al. (2007), Smets, & Wouters (2003, 2007) and Fernández-Villaverde (2010). Then, after specifying prior distributions, the likelihood function is calculated by using the Kalman filter. Finally, the posterior distribution is simulated through the Markov-Chain Monte Carlo (MCMC) procedure. The data set used to estimate the model is comprised of 15 key macroeconomic variables consisting of real GDP, real consumption, real government consumption, real investment, real exports and imports, the real effective exchange rate, the real wage, employment, the GDP deflator, the domestic lending rate and the CPI inflation. When estimating the model, the rest of the world is reasonably approximated by the first 12 Euro area (EA) countries. The EA series include GDP, the GDP deflator and the 12-month Euribor. Data are taken from databases and publications by the Statistical Office of the European Union (EUROSTAT), the Slovenian Statistical Office (SORS) and the Bank of Slovenia (BS). The parameters that are not estimated are calibrated using standard values in the literature or they are computed matching some relevant data moments for the Slovenian economy.

The second chapter makes use of a DSGE model from the first chapter. The methodology used to compare alternative fiscal rules involves several steps, and depends on the research questions addressed. I begin the analysis with an estimation of a DSGE using Slovenian macroeconomic data for the period of 1995-2014. Since no specific fiscal rules were put in place in Slovenia between this period, the benchmark model assumes the simplest structure for government consumption as AR(1) process. After estimation, I evaluate fiscal rules in three different ways. First, I analyse the properties of fiscal rules by means of a standard impulse response analysis. Second, I explore the implications of the alternative fiscal rules for macroeconomic volatility. For this purpose, I generate times series of the model's structural shocks from normal distributions with standard deviations equal to the posterior means, with each time series consisting of 200 observations. Using these randomly generated shocks, I simulate the paths for four variables of interest: real GDP growth, government consumption growth, budget balance and public debt employing the estimated DSGE model with the AR(1) process for government consumption replaced by the fiscal rule. I repeat this procedure 10000 times. For each simulation run, I calculate the standard deviation of the output growth, government consumption growth, budget balance and public debt. This gives me 10000 standard deviations for these four variables. Finally, I compute the average of the standard deviation of variable of interest over each of the 10000 simulated variable paths. The final exercise is to show how the selected macroeconomic variables might have evolved had fiscal rules discussed in this chapter been used as a guideline for fiscal policy in Slovenia.

In the third chapter, we continue to use the DSGE model presented in the preceding chapters and augment it with electricity price elements. More specifically, electricity is either directly consumed by households or used as an input of production. This required several modifications to the baseline model. In order to set up model simulations, the key challenge of this chapter is to calibrate parameters pertaining to the electricity block of the model. The calibration procedure is described in detail in Section 3.3.

Structure and contents of the dissertation

The core part of this dissertation consists of three chapters. Chapter 1 presents the estimated DSGE model for the Slovenian economy. In addition, to illustrate the usefulness of the model in structural business cycle analysis, role of various shocks in explaining macroeconomic fluctuations in the Slovenian economy, for the period 1995-2014, is discussed. Chapter 2 uses a DSGE model from the first chapter to evaluate alternative forms of fiscal rules for macroeconomic stabilization. Chapter 3 develops a DSGE model suitable for carrying out electricity sector related analyses for the Slovenian economy.

The first chapter presents the estimation of a DSGE model for the Slovenian economy. This chapter is organized in the following way: First, I motivate the study. Section 1.2 presents the benchmark model together with its extensions. Section 1.3 presents the estimation methodology and discusses the calibration of the model, choice of priors and presents the data used in the estimation, along with the data sources and measurement assumptions. Section 1.4 contains the estimation results and evaluation. Section 1.5 deals with the impulse response analysis of the various shocks and their contribution to the developments in the Slovenian economy. Section 1.6 concludes with a summary of the main findings and gives some policy recommendations.

The second chapter employs the estimated DSGE model from the first chapter to evaluate the macroeconomic effects of alternative forms of fiscal rules. This chapter proceeds as follows: In the introduction, I first motivate the analysis. The next section provides a background to fiscal rules by presenting a brief overview of the recent reforms of the E(M)U fiscal framework. Section 2.3 briefly presents the model on which the study is built upon, along with the parametrization strategy. Section 2.4 specifies the fiscal rules whose performance is evaluated and discuss the results once the rules have been implemented in the model. Finally, Section 2.5 concludes and draws some policy implications.

The third chapter, which develops a DSGE model with electricity, is organized as follows: Section 3.2 sets up the model. Section 3.3 describes the calibration process with special focus on electricity sector related parameters. Section 3.4 discusses results from some hypothetical simulations using impulse response functions, and Section 3.5 concludes.

Although each of the chapters includes a pertinent introduction and conclusion, the dissertation also includes a general introduction and conclusion. The latter is included in the conclusion chapter and contains the main findings and discussion of the results. The following chapter includes the list of references, while the last chapter consists of appendices, including a thorough abstract of the dissertation in the Slovenian language.

1 DECOMPOSING THE SLOVENIAN BUSINESS CYCLE: EVIDENCE FROM AN ESTIMATED DSGE MODEL[6]

1.1 Introduction

New-Keynesian dynamic stochastic general equilibrium (DSGE) models are widely used tools for macroeconomic analysis. The key feature of this class of models is that they are derived from the microeconomic foundations meaning that they assume optimizing agents which usually form rational expectations and maximize their objective functions subject to their respective

[6]The content of this chapter was accepted for the publication in Economic and Business Review (EBR) Journal. I would like to thank the editor and the two anonymous referees who reviewed the earlier version of this manuscript and provided valuable suggestions and comments.

constraints in the presence of imperfect competition and nominal rigidities.[7] In recent years there have been many theoretical and empirical contributions developing and estimating DSGE models. The most influential papers in this area include Clarida et al. (1999, 2001), Beningo & Beningo (2003), Galí & Monacelli (2005), Christiano et al. (2005), Smets & Wouters (2003, 2007), Adolfson et al. (2007) and many others. Although the literature on the estimation of DSGE models and the subsequent use of these models to study macroeconomic fluctuations in various countries has rapidly expanded in recent years, no attempt has as yet been made to estimate a New-Keynesian DSGE model for Slovenia, at least to the best of my knowledge.[8] This chapter therefore seeks to fill this gap by presenting an estimated DSGE model for the Slovenian economy.

The model that I use was inspired in the work of Adolfson et al. (2007) and Masten (2010). Masten (2010) extended the baseline model of Adolfson et al. (2007) in two directions, namely by (i) adapting the model to the small open economy case within the Euro area and (ii) enriching the fiscal block of the model. I use a Bayesian approach to estimate key model parameters on 15 time series for Slovenia: GDP, consumption, investment, exports, imports, government consumption, real effective exchange rate, real wage, employment, GDP deflator, CPI price index, short-run interest rate, and three foreign variables (that is output, inflation and interest rate), which refer to the first 12 Euro area countries.

With this chapter I want to contribute to the large literature on estimated DSGE models by applying the Bayesian method to the estimation of the DSGE model for the Slovenian economy and therefore presenting evidence for an additional country on the estimates of the structural parameters, and by identifying the shocks responsible for the recent recession and the key sources of macroeconomic fluctuations in Slovenia.

This chapter addresses the following research questions: (1) What are the estimates of structural parameters and shocks for the Slovenian economy?; (2) What are the main driving forces of the business cycle in Slovenia, with special attention given to the recession periods?; (3) What are the similarities and differences between the 2008-2009 and 2012-2013 recession in terms of structural shocks?; (4) What structural shocks are the most important contributors to the recovery of economic activity after 2013?

After the estimation, I first present the estimates of structural parameters. I then perform several checks of the model's empirical performance. Specifically, I evaluate how well the model fits the data. To do so, I compare the actual data with the one-sided predicted values from the

[7] For further information on the New-Keynesian models, see, for example, Galí (2008) and Woodford (2003).

[8] Despite their wide use, DSGE models have also certain drawbacks. The most problematic issues which are currently much discussed in the literature are mainly concerned with: (i) unrealistic assumptions (e.g. Ricardian equivalence, rational expectations hypothesis, infinitely-lived households, etc.), (ii) unconvincing method of estimation (which is a combination of calibration and Bayesian estimation), (iii) questionable assumption about the structural parameters that are assumed to be invariant to policy changes, (iv) issue related with the use of revised or real-time data when estimating the model, and (v) poor performance during the recent crisis. For more detailed discussion of these issues, see Romer (2016), Blanchard (2016) and the other contributions (see Blanchard (2017) for an extensive list of references). See also Christiano et al. (2018) who offer a critical overview of DSGE models. Despite these shortcomings, I decided to use a DSGE framework as I believe that it is flexible enough to be used for the purposes of this dissertation, while other models are more limited in terms of their ability to fully address the research questions under study.

model. Next, I calculate statistics of the data generated by the estimated model and compare them with those based on the actual data. Finally, I look at the smoothed estimates of the shock innovation paths to check whether they look stationary. In the last part of this chapter, I apply the estimated DSGE model to analyse the contribution of the structural shocks on business cycle fluctuations in the Slovenian economy. I proceed here in three steps. First, using traditional impulse response analysis, I look at the partial effects of the most important shocks included in the model on key macroeconomic variables. Second, to assess how much of the volatility of the observed variables can be explained by the shocks included in the model, I also produce variance decomposition analysis. Finally, I compute historical decompositions of GDP growth and its main components in terms of various structural shocks of the model to examine the importance of respective shocks in explaining the observed macroeconomic dynamics over the sample period, with particular attention to the recent recessionary periods.

Previewing the results, I find that investment-specific technology shocks mostly accounted for a significant portion of the drop in output growth from 2008 onwards. This result accords with a drop in foreign and domestic orders followed by a decline in investment (mostly at the beginning of the crisis) and the large amount of losses of the corporate sector that accumulated on balance sheets of the banks in the form of non-performing bad loans, further contributing to a contraction of lending activity, which in turn reduced investment and impeded economic activity. Furthermore, consumption preference and export mark-up shocks were another sources that contributed negatively to GDP growth, most likely reflecting the reduction in households' income (in combination with the precautionary saving) and the fall in exports due to the deterioration of external competitiveness, as wages increased faster than productivity before the crisis years, respectively. The results also suggest that fiscal shocks had a stimulating impact during the first stage of the crisis. However, starting from 2010 there was a turnaround in fiscal policy due to austerity measures adopted to consolidate public finances. The slowdown in GDP growth was also accompanied by permanent (unit-root) technology shocks that could be considered as associated with the lack of productivity-enhancing and other structural reforms in the run-up to the crisis. By contrast, the historical decomposition suggests that transitory (stationary) technology shocks were stimulative for GDP growth from 2013 onwards, which may be interpreted as resulting from a temporary greater tendency of the corporate sector to take restructuring measures in response to the crisis to enhance its technology and production efficiency. Finally, the results show that the recovery phase after 2013 is explained mainly by consumption preference shocks, which could be explained by the increased consumer confidence, resolution of banking system problems, as well as by the improvement in the labour market situation.

In terms of policy recommendations, Slovenia should speed up implementation of structural reforms. This policy advice emerges directly from the results of historical decompositions. It can be observed that the permanent technology shocks which could be considered as associated with structural reforms had mainly negative impact on GDP growth in the recent years, clearly indicating that the pace of structural reforms slowed down. Slovenia is currently facing several challenges, probably the most important being those related to population ageing and shortage of labour force. Therefore, in the near future, the government should undertake labour market reforms, reforms in the education system and adopt appropriate migration policies. Other reforms such as those focused on the overall business environment and taxation would also be much needed and appreciated.

The rest of the chapter is organized as follows. Section 1.2 presents the model. Section 1.3 presents the estimation methodology and discusses the calibration of the model, the choice of priors, and presents the data used in the estimation. Section 1.4 contains the estimation results and evaluation, which are followed by an analysis of the impulse responses of the various structural shocks and their contribution to the developments in the Slovenian economy in Section 1.5. Section 1.6 concludes with a summary of the main findings.

1.2 The model

As mentioned in the introduction, to describe the Slovenian economy, I use a DSGE model presented in Adolfson et al. (2007) and Masten (2010), which is an extended version of basic closed-economy new-Keynesian models, including the benchmark models of Christiano et al. (2005), Altig et al. (2011), and Smets & Wouters (2003, 2007). The model economy consists of households, domestic goods producing firms, importing consumption and importing investment firms, exporting firms, a government which conducts fiscal policy, and an exogenous foreign economy. As it is common in the DSGE literature, the model incorporates several real and nominal rigidities, such as habit persistence in consumption, variable capacity utilization of capital and investment adjustment costs, as well as the price and wage stickiness. The stochastic dynamics of the model is driven by 16 exogenous structural shocks. The shocks considered are: permanent (unit-root) technology, transitory (stationary) technology, investment-specific technology, markup shocks (domestic, imported consumption, imported investment and export markup shocks), consumption preference and labour supply shocks, asymmetric technology, risk premium, foreign VAR shocks (foreign output, inflation and interest rate shocks) and fiscal shocks (rate of transfers to households and government spending shocks). One feature of the model worth noting is that it includes a stochastic unit-root technology shock, which implies a common trend in the real variables of the model. Consequently, the model can be estimated with raw data without any pre-filtering. In the following, I summarize the main features of the model. To this end, I follow quite closely the mode of presentation from Section 2 of Adolfson et al. (2014).[9]

1.2.1 Supply side of the economy

1.2.1.1 Domestic firms

The domestic firms use labour together with capital to produce intermediate goods Y_i, which are sold to the final good producer. The production function of the final good firm is of the Dixit-Stiglitz form:

$$Y_t^d = \left[\int_0^1 \left(Y_{i,t}^d \right)^{\frac{1}{\lambda_t^d}} di \right]^{\lambda_t^d}, \quad \lambda_t^d \geq 1, \tag{1}$$

[9] The detailed description of the model (including the first order conditions) is available in Adolfson et al. (2007).

where $\lambda_{d,t}$ is a stochastic process determining the time-varying markup in the domestic goods market. The final good producers operate in a perfectly competitive environment, taking the prices of the intermediate goods $P^d_{i,t}$ and final goods P^d_t as given. The production function for each intermediate good firm i which operates under monopolistic competition is of the Cobb-Douglas type:

$$Y_{i,t} = z_t^{1-\alpha}\epsilon_t K^{\alpha}_{i,t} H^{1-\alpha}_{i,t} - z_t\phi, \tag{2}$$

where $H_{i,t}$ denotes homogeneous labour input hired by firm i, and $K_{i,t}$ is the amount of capital services used by firm i, which can differ from capital stock since the model assumes a variable capital utilization rate. Furthermore, z_t is permanent (unit-root) technology shock, whereas ϵ_t is a transitory (stationary) technology shock. The term $z_t\phi$ indicates fixed costs, which grow with the technology rate. Fixed costs are set in such a way that profits are zero in steady state. Cost minimization yields the following nominal marginal cost function for intermediate firm i:

$$MC^d_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\left(R^k_t\right)^{\alpha} W_t^{1-\alpha}\frac{1}{z_t^{1-\alpha}}\frac{1}{\epsilon_t}, \tag{3}$$

where R^k_t is the gross nominal rental rate per unit of capital, R_t is the gross nominal interest rate, and W_t is the nominal wage rate per unit of aggregate, homogeneous labour $H_{i,t}$. Besides solving the cost minimization problem, intermediate good firms have to decide on price for their output. The model assumes the Calvo type staggered-price setting. This means that at each period, each firm faces a random probability $(1-\xi_d)$ that it can reoptimize its price. The reoptimized price is denoted $P^{d,opt}_t$. With probability ξ_d a firm is not allowed to set its prices optimally, and its price is then set according to the following indexation rule (Smets & Wouters, 2003):

$$P^d_{t+1} = \left(\pi^d_t\right)^{\kappa_d} P^d_t,$$

where $\pi^d_t = P^d_t/P^d_{t-1}$ is the (gross) inflation rate and κ_d is an indexation parameter. The optimization problem of a firm setting a new price in period t is the following:

$$\max_{P^{d,opt}_t} \mathbb{E}_t \sum_{s=0}^{\infty}\left(\beta\xi_d\right)^s \upsilon_{t+s}\left[\begin{array}{c}\left(\pi^d_t\pi^d_{t+1}...\pi^d_{t+s-1}\right)^{\kappa_d} P^{d,opt}_t Y^d_{i,t+s} \\ -MC^d_{i,t+s}\left(Y^d_{i,t+s} + z_{t+s}\phi\right)\end{array}\right], \tag{4}$$

where $\left(\beta\xi_d\right)^s \upsilon_{t+s}$ denotes the stochastic discount factor, which is used to make profits conditional upon utility. β is the discount factor, and υ_t denotes the marginal utility of households' nominal income in period $t+s$, which is exogenous to the intermediate firms.

1.2.1.2 Importing and exporting firms

The importing sector consists of two types of firms: firms which import consumption goods and firms which import investment goods. There is a continuum of importing firms, indexed by $i \in (0,1)$. These firms buy a homogeneous good in the world market at price P^*_t and transform it into a differentiated consumption $C^m_{i,t}$ or investment good $I^m_{i,t}$. In addition, there is also a continuum $i \in (0,1)$ of exporting firms that buy a homogeneous good on the domestic market and transform it into a differentiated exported good which is sold on the foreign market. The marginal cost of importing and exporting firms are P^*_t and P_t, respectively. The aggregate import consumption, import investment and export good is a composite of a continuum of i differentiated imported consumption, imported investment and exported goods, each supplied by a different firm, which follows the CES function:

$$C_t^m = \left[\int_0^1 \left(C_{i,t}^m\right)^{\frac{1}{\lambda_t^{m,c}}} di\right]^{\lambda_t^{m,c}} \qquad I_t^m = \left[\int_0^1 \left(I_{i,t}^m\right)^{\frac{1}{\lambda_t^{m,i}}} di\right]^{\lambda_t^{m,i}} \qquad X_t = \left[\int_0^1 \left(X_{i,t}\right)^{\frac{1}{\lambda_t^{x}}} di\right]^{\lambda_t^{x}}, \tag{5}$$

where $1 \leq \lambda_t^j < \infty$ for $j = \{mc, mi, x\}$ is the time-varying flexible-price mark-up in the import consumption (mc), import investment (mi) and export (x) sector. The model assumes monopolistic competition among importers and exporters and Calvo-type staggered price setting. The price setting problems are completely analogous to that of the domestic firms in Equation (4). From the optimization problems four specific Phillips curves, determining inflation in the domestic, import consumption, import investment and export sectors, can be derived.

1.2.2 Demand side of the economy

1.2.2.1 Households

In the model economy there is also a continuum of households $j \in (0,1)$, which attain utility from consumption and leisure. The households decide on their current level of consumption and their domestic and foreign bond holdings. They also choose the level of capital services provided to the firms, their level of investment and their capital utilization rate. The households can increase their capital stock by investing in additional physical capital, taking one period to come in action, or by directly increasing the utilization rate of the capital at hand. The j^{th} household's utility function is:

$$\mathbb{E}_0^j \sum_{t=0}^{\infty} \beta^t \left[\zeta_t^c \ln\left(C_{j,t} - bC_{j,t-1}\right) - \zeta_t^h A_L \frac{\left(h_{j,t}\right)^{1+\sigma_L}}{1+\sigma_L}\right], \tag{6}$$

where $C_{j,t}$ and $h_{j,t}$ denotes levels of real consumption and labour supply of household j, respectively. A_L is a constant representing the weight that the worker attaches to disutility of work. The model also allows for habit formation in consumption by including $bC_{j,t-1}$. ζ_t^c and ζ_t^h are preference shocks, consumption preference shock and labour supply shock, respectively. The aggregate consumption C_t is a CES index of domestic C_t^d and imported C_t^m consumption goods:

$$C_t = \left[\left(1-\omega_c\right)^{1/\eta_c} \left(C_t^d\right)^{(\eta_c-1)/\eta_c} + \omega_c^{1/\eta_c} \left(C_t^m\right)^{(\eta_c-1)/\eta_c}\right]^{\eta_c/(\eta_c-1)}, \tag{7}$$

where ω_c is the share of imported consumption goods in total consumption, and η_c is the elasticity of substitution between domestic and imported consumption goods. The corresponding consumer price index is given by:

$$P_t^c = \left[\left(1-\omega_c\right)^{1/\eta_c} \left(P_t^d\right)^{1-\eta_c} + \omega_c^{1/\eta_c} \left(P_t^{m,c}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)}. \tag{8}$$

The model also assumes that households can purchase investment goods in order to increase their capital stock. The law of motion of capital is given by:

$$\bar{K}_{t+1} = (1-\delta)\,\bar{K}_t + \Upsilon_t F\left(I_t, I_{t-1}\right) + \Delta_t, \tag{9}$$

where $\bar{K}_t$ is a physical capital stock, δ is the depreciation rate of capital stock, $F(I_t, I_{t-1})$ is a function that transforms investment into capital. Following Christiano et al. (2005), $F(I_t, I_{t-1})$ is of the following form:

$$F(I_t, I_{t-1}) = \left[1 - \tilde{S}(I_t, I_{t-1})\right] I_t, \tag{10}$$

where $\tilde{S}$ determines the investment adjustment costs through the estimated parameter $\tilde{S}''$. Υ_t denotes the investment-specific technology shock and Δ_t represents either newly bought capital if it is positive or sold capital if it is negative. The investment (I_t) is a bundle between domestic and imported investment goods (I_t^d and I_t^m, respectively):

$$I_t = \left[(1-\omega_i)^{1/\eta_i} \left(I_t^d\right)^{(\eta_i-1)/\eta_i} + \omega_i^{1/\eta_i} \left(I_t^m\right)^{(\eta_i-1)/\eta_i}\right]^{\eta_i/(\eta_i-1)}, \tag{11}$$

where ω_i denotes the share of imported investment goods in total investment, and η_i is elasticity of substitution between domestic and imported investment goods. It is worth noting that domestically produced consumption and investment goods have the same price P_t^d. The aggregate investment price index is therefore given by:

$$P_t^i = \left[(1-\omega_i)\left(P_t^d\right)^{1-\eta_i} + \omega_i \left(P_t^{m,i}\right)^{1-\eta_i}\right]^{1/(1-\eta_i)}. \tag{12}$$

Furthermore, the model assumes that each household is a monopolistic supplier of differentiated labour service, which implies that they can determine their own wage. Each household sells its labour $h_{j,t}$ to a firm which transforms it into a homogeneous input good H_t according to the following production function:

$$H_t = \left[\int_0^1 (h_{j,t})^{\frac{1}{\lambda_w}} dj\right]^{\lambda_w}, \ \lambda_w \geq 1, \tag{13}$$

where λ_w is the wage markup. The demand function for each differentiated labour service is given by:

$$h_{j,t} = \left[\frac{W_{j,t}}{W_t}\right]^{\frac{\lambda_w}{1-\lambda_w}} H_t. \tag{14}$$

Following Erceg et al. (2000) and Christiano et al. (2005), the households are subject to the Calvo wage rigidities, which means that in every period each household faces a random probability $1-\xi_w$ that it can change its nominal wage. If a household is allowed to re-optimize its wage, it will set its wage to W_t^{opt} taking into account the probability ξ_w that the wage will not be re-optimized in the future. The households that cannot re-optimize set their wages according to the following indexation rule:

$$W_{j,t+1} = (\pi_t^c)^{\kappa_w} \mu_{z,t+1} W_{j,t}, \tag{15}$$

where κ_w is an indexation parameter, π_t^c is the inflation rate measured by the consumer price index, and $\mu_{z,t} = z_t/z_{t-1}$ is the growth rate of the unit-root technology shock. The household j that can re-optimize solves the following optimization problem:

$$\max_{W_{j,t}^{opt}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h A_L \frac{(h_{j,t+s})^{1+\sigma_L}}{1+\sigma_L} \\ +v_{t+s}\left(1-\tau^y+\tau_{t+s}^{tr}\right)\left(\pi_t^c \dots \pi_{t+s-1}^c\right)^{\kappa_w} \\ \times \left(\mu_{z,t+1} \dots \mu_{z,t+s}\right) W_{j,t}^{opt} h_{j,t+s} \end{array} \right\}, \tag{16}$$

where τ^y is a labour income tax and τ_t^{tr} is a time-varying rate of social transfers to households defined in more detail in Subsection 2.3.

1.2.3 Monetary policy

The monetary policy is modelled in a highly simplified way. It is assumed that the domestic interest rate (R_t) depends on the exogenously given foreign interest rate (R_t^*) adjusted for the risk premium on foreign bonds ($\Phi\left(a_t, \tilde{\phi}_t\right)$):[10]

$$R_t = R_t^* \Phi\left(a_t, \tilde{\phi}_t\right), \tag{17}$$

where the risk premium, which is defined through the following function:

$$\Phi\left(a_t, \tilde{\phi}_t\right) = e^{-\tilde{\phi}_a(a_t - \bar{a}) + \tilde{\phi}_t}, \tag{18}$$

depends on the aggregate net foreign asset position of the domestic economy (a_t) and exogenous risk premium shocks ($\tilde{\phi}_t$).[11] The inclusion of risk premium is necessary to ensure a well-defined steady state in the model (Schmitt-Grohé & Uribe, 2003).

[10]In Adolfson et al. (2007), the interest rate is determined according to a simple rule (expressed in log-linear form):

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)\left(\hat{\bar{\pi}}_t^c + r_\pi\left(\hat{\pi}_{t-1}^c - \hat{\bar{\pi}}_t^c\right) + r_y \hat{y}_{t-1} + r_x \hat{x}_{t-1}\right) + r_{\Delta\pi}\Delta\hat{\pi}_t^c + r_{\Delta y}\Delta\hat{y}_t + \varepsilon_{R,t},$$

where $\hat{R}_t$ is the short-rate interest rate, $\hat{\pi}_t^c$ the CPI inflation rate, $\hat{\bar{\pi}}_t^c$ a time-varying inflation target, $\hat{y}_t$ the output gap, $\hat{x}_t$ denotes the real exchange rate, and $\varepsilon_{R,t}$ is an interest rate shock.

[11] Besides joining the European Monetary Union (EMU) in 2007, Slovenia went through different monetary regimes since its independence in 1991: money based stabilization policy (1991-1995), price and real exchange rate stability dual targeting policy (1996-2001), and exchange rate based stabilization policy and accession to ERM 2 exchange rate mechanism and EMU (2001-2007) (Caprirolo & Lavrač, 2003). Because these would be very difficult to implement in the model, I am not modelling any break in the conduct of monetary policy when estimating the model. Rather, I follow an uncomplicated way of monetary policy inclusion into the model structure. That is, I keep only a modified UIP condition (17) on the monetary side without specifying any particular form of monetary policy rule for the period before 2007, when Slovenia run an independent monetary policy. Of course, for the years before 2007 (or at least 2004Q3, when Slovenia entered the ERM 2), an additional term, $-\Delta S_{t+1}$, capturing the nominal exchange rate fluctuations, must be added on the right-hand side of Equation (17). In addition, the terms of trade channel would be affected by the nominal exchange rate. In such a setting the endogenously determined nominal exchange rate may reduce or amplify the impact of structural shocks, depending on their nature. Based on the findings presented in Cúrdia et al. (2012), applying a more adequate approach to modelling monetary policy may also improve the fit of the model. I initially included exchange rate as an additional variable into the model, but due to model solvability problems (i.e. more variables than equations) I again restricted with the simple version, as described above. In other words, in order to guarantee solvability of the model, an explicit monetary policy rule must be incorporated into the model structure. Despite these simplifications, the model in such a structure fits the data, including the short-term nominal interest rates, reasonably well. It is also worth noting that similar approach neglecting existence of diverse monetary policies and flexible exchange rates prior to the EMU-start was used in the literature (see, for example, Adolfson et al. (2007), Almeida (2009), Smets & Wouters (2003), Marcellino & Rychalovska (2014) among others). The authors estimated their models under the implicit assumption that even before the establishment of the currency area there was a common monetary policy in the European Union. Finally, as a robustness check I re-estimated the model using the data for the period 2004Q3 onwards, when Slovenia entered the ERM 2. My analysis reveals that in this case parameter estimates do not substantially vary from the estimates reported in Tables (3) and (4) in the main text. But what is more important, I find that the main results reported in the chapter (e.g., those of the historical decompositions) persist. I choose not to report this robustness check in the chapter to save space, but it is available upon request from the author.

1.2.4 Fiscal policy

The government in this economy collects taxes, issues debt and uses revenues for government consumption, transfers to households and interest on outstanding debt. The resulting government budget constraint can be expressed as:

$$B_{t+1} + T_t = R_{t-1}B_t + TR_t + P_t^d G_t \Leftrightarrow B_{t+1} = B_t + DEF_t, \tag{19}$$

where B_t denotes the public debt and DEF_t is the government deficit, which is defined as the difference between the government expenditures GEX_t and total tax revenues T_t:

$$DEF_t = GEX_t - T_t. \tag{20}$$

The government tax revenues consist of taxes on private consumption, as well as on labour income and capital income:

$$\begin{aligned} T_t &= \tau^c P_t^c C_t + \tau^y W_t H_t \\ &+ \tau^k \left[(R_{t-1} - 1) B_t + R_t^k K_t + \left(R_{t-1}^* \Phi \left(a_{t-1}, \tilde{\phi}_{t-1} \right) - 1 \right) B_t^* + \Pi_t \right], \end{aligned} \tag{21}$$

with τ^c, τ^y and τ^k being the tax rates on private consumption, labour income and capital income, respectively, which are assumed to be fixed. In the above expression, Π_t are total profits, which are equal to the sum of profits earned by domestic, importing and exporting firms, Π_t^d, Π_t^m and Π_t^x, respectively:

$$\Pi_t = \Pi_t^d + \Pi_t^m + \Pi_t^x, \tag{22}$$

where:

$$\begin{aligned} \Pi_t^d &= P_t^d \left(C_t^d + I_t^d + G_t \right) + P_t^d \left(C_t^x + I_t^x \right) \\ &- MC_t^d \left(C_t^d + I_t^d + G_t + C_t^x + I_t^x \right) - MC_t^d z_t \phi \end{aligned} \tag{23}$$

$$\Pi_t^m = P_t^{m,c} C_t^m + P_t^{m,i} I_t^m - P_t^* \left(C_t^m + I_t^m \right) \tag{24}$$

and:

$$\Pi_t^x = P_t^x \left(C_t^x + I_t^x \right) - P_t^d \left(C_t^x + I_t^x \right). \tag{25}$$

Furthermore, the government expenditures are given by:

$$GEX_t = TR_t + P_t^d G_t + (R_{t-1} - 1) B_t, \tag{26}$$

where TR_t denotes transfers to households, G_t is government consumption of goods and services and $(R_{t-1} - 1) B_t$ stands for public debt interest payments. I assume that transfers to households are indexed to wages W_t and hours worked H_t with an exogenously given rate of transfers τ_t^{tr} according to the following expression (D'Auria et al., 2009):

$$TR_t = \tau_t^{tr} W_t H_t. \tag{27}$$

For the rate of transfers to households it is simply assumed that follow an AR(1) process (in deviations from its steady state):

$$\hat{\tau}_t^{tr} = \rho_{\tau^{tr}} \hat{\tau}_{t-1}^{tr} + \varepsilon_{\tau^{tr},t}. \tag{28}$$

Finally, government consumption follows the log-linear rule of the following form:[12]

$$\hat{g}_t = \rho_g \hat{g}_{t-1} - \phi_\pi \hat{\pi}_t^c - \phi_y \hat{y}_t - \phi_b \hat{b}_t - \phi_d \widetilde{def}_t + \varepsilon_{g,t}. \tag{29}$$

In this equation, $\hat{g}_t$ is the percentage deviation of real government consumption (stationarized with the unit-root technology level, z_t) from its steady state level, $\hat{\pi}_t^c$ is the CPI inflation, $\hat{y}_t$ reflects the output gap, $\hat{b}_t$ is the public debt and $\widetilde{def}_t$ denotes the government deficit which is expressed as a difference from its steady state, that is, $\widetilde{def}_t = def_t - def$. $\varepsilon_{g,t}$ defines the exogenous shock aimed at capturing discretionary changes in government consumption. ϕ_π, ϕ_y, ϕ_b and ϕ_d denote the feedback coefficients towards inflation, output gap, public debt and government deficit deviations, respectively. ρ_g reflects the degree of government consumption smoothing.

1.2.5 Market equilibrium

In equilibrium all markets clear. The market clearing condition for the domestic goods market is given by:

$$C_t^d + I_t^d + G_t + C_t^x + I_t^x \leq z_t^{1-\alpha} \epsilon_t K_t^\alpha H_t^{1-\alpha} - z_t \phi - a\left(u_t\right) \bar{K}_t, \tag{30}$$

where C_t^x and I_t^x are the foreign demand for export goods which follow CES aggregates with elasticity η_f. Furthermore, the net foreign assets' market clears when domestic investment in foreign bonds (denoted by B_t^*) equals the net position of exporting/importing firms:

$$B_t^* = P_t^x \left(C_t^x + I_t^x\right) - P_t^* \left(C_t^m + I_t^m\right) + R_{t-1}^* \Phi\left(a_t, \tilde{\phi}_t\right) B_t^*. \tag{31}$$

1.2.6 Foreign economy

Since the domestic economy is a small open economy, I assume that the foreign economy is exogenous. In particular, foreign output ($\hat{y}_t^*$), foreign inflation ($\hat{\pi}_t^*$) and foreign interest rate ($\hat{R}_t^*$) are exogenously modelled as an identified VAR model with two lags:[13]

$$\Phi_0 X_t^* = \Phi_1 X_{t-1}^* + \Phi_2 X_{t-2}^* + S_{x^*} \varepsilon_{x^*,t}, \tag{32}$$

[12] The specification for the fiscal rule is similar to those used by Erceg & Lindé (2013), with the only exception that they do not include the inflation rate.

[13] The foreign VAR model is estimated for the first 12 Euro area countries over the period 1995Q1-2014Q4 and includes the following variables: output (GDP at market prices, chain linked volumes (2005), million units of national currency); GDP deflator (GDP at market prices, price index (implicit deflator), 2005=100, national currency); interest rate (12-month money market interest rate in percent). To make the observed data consistent with the model's concepts, I adjusted the data before entering the VAR model. Specifically, I used HP-detrended log of GDP (I set the smoothing parameter to 1600, which is typically used with quarterly data), the demeaned first difference of the log of GDP deflator and the demeaned interest rate which is divided by 400. All data series are seasonally adjusted and adjusted by working days. The lag order of the VAR model was chosen using the Hannan-Quinn information criterion, which suggests an optimal lag order of two periods (Lütkepohl & Krätzig, 2004). I also removed variables with lowest t-ratios until all remaining variables had t-ratios greater than 2, which is often

where $X_t^* \equiv \left(\hat{\pi}_t^*, \hat{y}_t^*, \hat{R}_t^*\right)'$, $\varepsilon_{x^*,t} \sim \mathcal{N}\left(0, I_{x^*}\right)$, S_{x^*} is a diagonal matrix with standard deviations and $\Phi_0^{-1} S_{x^*} \varepsilon_{x^*,t} \sim \mathcal{N}\left(0, \Sigma_{x^*}\right)$.

1.2.7 Structural shocks

In total, the dynamics of the model is driven by 16 exogenous shock processes that are assumed to be characterized in log-linearized form by the univariate representation:

$$\hat{\xi}_t = \rho_\xi \hat{\xi}_{t-1} + \varepsilon_{\xi,t}, \quad \varepsilon_{\xi,t} \overset{iid}{\sim} N\left(0, \sigma_\xi^2\right), \tag{33}$$

where $\xi_t = \left\{\mu_{z,t}, \epsilon_t, \lambda_t^j, \zeta_t^c, \zeta_t^h, \Upsilon_t, \tilde{\phi}_t, \tilde{z}_t^*, \tau_t^{tr}, \varepsilon_{g,t}\right\}$ for $j = \{d, mc, mi, x\}$. $\varepsilon_{g,t}$ is assumed to be a white noise process (that is, $\rho_{\varepsilon_g} = 0$). There are also three foreign shocks (that is, foreign output, foreign inflation and foreign interest rate shock) provided by the exogenous (pre-estimated) foreign VAR model.

1.3 Model solution and estimation

In this section, I present how the DSGE model is solved and estimated.

1.3.1 Model solution

The model presented in the previous section consists of a set of optimality conditions and laws of motion of the shock processes. Since the model comprises the unit-root technology shock that induces a stochastic trend in the levels of the real variables, the first step prior to model solution is rendering the model stationary. To this end all real variables are divided with the trend level of technology z_t. The resulting stationary variables are then denoted by lower-case letters, that is, $x_t = \frac{X_t}{z_t}$ for a generic variable x_t. I then proceed with the log-linearisation[14] to the model's equations of the transformed model around the deterministic steady state[15], where

used in applied work. The estimated foreign VAR model is, therefore, given by:

$$\begin{aligned}
\hat{\pi}_t^* &= 0.028\hat{y}_{t-1}^* + 0.121\hat{\pi}_{t-1}^* + 0.279\hat{\pi}_{t-2}^* + \varepsilon_{\pi^*,t} \\
\hat{y}_t^* &= 1.667\hat{y}_{t-1}^* - 0.698\hat{y}_{t-2}^* + \varepsilon_{y^*,t} \\
\hat{R}_t^* &= 1.190\hat{R}_{t-1}^* + 0.321\hat{y}_{t-1}^* - 0.306\hat{y}_{t-2}^* - 0.271\hat{R}_{t-2}^* + \varepsilon_{R^*,t}.
\end{aligned}$$

.

[14] However, it is important to notice that dynamics in the log-linearized model is only approximation of the true non-linear dynamics. Therefore, studying the log-linearized models is only valid for small deviations from the model's steady state. For a complete list of the log-linearized equations of the model see, Appendix D.

[15] I compute the non-stochastic steady state of the model following the procedure described in Adolfson et al. (2007). It is important to note that the steady state also depends on estimated parameters. For this reason, when estimating the model, it is of great importance to take into account parameter dependence by using model-local variables. For further discussion, see Pfeifer (2014a), Remark 4 (Parameter dependence and the use of model-local variables).

the variables are expressed as logarithmic deviations from their steady state values, that is $\hat{x}_t = \frac{x_t - x}{x} \approx \ln x_t - \ln x$, where x denotes the steady state value of a generic variable x_t. Once the model has been stationarized and log-linearized, it can be written in the following compact form:

$$\mathbb{E}_t \left\{ \alpha_0 \Gamma_{t-1} + \alpha_1 \Gamma_t + \alpha_2 \Gamma_{t+1} + \beta_2 \Psi_{t+1} + \beta_1 \Psi_t \right\} = 0, \tag{34}$$

where Γ_t is a vector of endogenous variables, Ψ_t is a vector of exogenous variables, and α_0, α_1, α_2, β_1 and β_1 are coefficient matrices. It is assumed that Ψ_t evolves according to:

$$\Psi_t = \rho \Psi_{t-1} + \varepsilon_t \quad \varepsilon_t \sim N\left(0, \Sigma\right). \tag{35}$$

I use Dynare 4.4.3[16] to solve the model. The solution of the model takes the form:[17]

$$\Gamma_t = A\Gamma_{t-1} + B\Psi_t. \tag{36}$$

1.3.2 Data and measurement equations

For estimation purposes the solved model can be written in the following state-space form (Hamilton, 1994):

$$\xi_{t+1} = F\xi_t + \upsilon_{t+1} \tag{37}$$

and:

$$\tilde{Y}_t = A'x_t + H'\xi_t + \omega_t. \tag{38}$$

The first equation is called the state equation, whereas the second is called the observation (measurement) equation. The symbols appearing in (37) and (38) have the following meaning: $\tilde{Y}_t$ is an $(n \times 1)$ vector of observed variables at time t, ξ_t is an $(r \times 1)$ vector of unobserved variables at time t (also referred to as state vector) and x_t is a $(k \times 1)$ vector with exogenous or predetermined variables (e.g. a constant). Furthermore, F, A' and H' are matrices of dimension $(r \times r)$, $(n \times k)$ and $(n \times r)$, respectively. The $(r \times 1)$ vector υ_t and the $(n \times 1)$ vector ω_t are uncorrelated, normally distributed white noise vectors, therefore:

$$\mathbb{E}\left(\upsilon_t \upsilon_\tau'\right) = \begin{cases} Q & \text{for } \tau = t \\ 0 & \text{otherwise} \end{cases}$$

$$\mathbb{E}\left(\omega_t \omega_\tau'\right) = \begin{cases} R & \text{for } \tau = t \\ 0 & \text{otherwise,} \end{cases}$$

where Q and R are $(r \times r)$ and $(n \times n)$ matrices, respectively. The disturbances υ_t and ω_t are assumed to be uncorrelated at all lags:

$$\mathbb{E}\left(\upsilon_t, \omega_\tau'\right) = 0 \quad \text{for all } t \text{ and } \tau. \tag{39}$$

[16] Dynare is a software package for solving and estimating DSGE models. For more information regarding Dynare refer to the official Dynare web page `http://www.dynare.org` and see Mancini Griffoli (2011), as well as Adjemin, Bastani, Karamé, Juillard, Maih, Mihoubi, Perendia, Pfeifer, Ratto & Villemot (2014).

[17] Dynare uses solution algorithms proposed by Klein (2000) and Sims (2002). For a detailed look at what exactly is going on behind the scenes of Dynare's computations, the interested reader is referred to Villemot (2011).

In what follows, I describe how the raw data were converted to the form used in estimation. In addition, I present the exact measurement equations that are employed to relate the observed data to the model state variables. The estimates are based on quarterly Slovenian macroeconomic data covering the period 1995Q1-2014Q4. I employ the following 14 variables as observables:[18] the GDP deflator (P_t^d), the real wage (W_t/P_t^d), consumption (C_t), investment (I_t), government consumption (G_t), the real exchange rate (x_t), the short-run interest rate (R_t), employment[19] (E_t), GDP (Y_t), exports (X_t), imports (M_t), the CPI price index (P_t^c), foreign output (for the first 12 Euro area countries) (Y_t^*), the foreign GDP deflator (for the first 12 Euro area countries) (P_t^*) and the foreign interest rate (12-month money market interest rate of the Euro area) (R_t^*). Regarding the foreign variables, GDP for the first 12 Euro area countries is used for foreign output, and the GDP deflator for the first 12 Euro area countries is used for foreign inflation, while the foreign interest rate refers to the 12-month money market interest rate of the Euro area. Data come from four different sources. Data on the employment and gross wages are taken from the Statistical Office of the Republic of Slovenia. The sources for domestic interest rate are the Bank of Slovenia and the Institute of Macroeconomic Analysis and Development of the Republic of Slovenia. The rest of the data are taken from Eurostat. Since the model comprises a stochastic unit root technology shock that induces a common stochastic trend in the real variables of the model, I use first differences to make these variables stationary. When estimating the model, the following variables are matched in growth rates measured as quarter-to-quarter log-differences: GDP, consumption, investment, exports, imports, government consumption, real wage, GDP deflator, CPI price index, foreign output and foreign GDP deflator. The rest of the variables are used in levels: domestic and foreign interest rate, employment and real exchange rate. The real wage is calculated as the nominal gross wage per employee deflated by the GDP deflator. All interest rates are divided by 4 to express them in quarterly rates consistent with the variables in the model. The stationary variables, x_t and E_t, are measured as follows: I take the logarithm of real exchange rate and remove a linear trend, so that it is expressed in percentage deviations from the trend, consistently with the model concepts, that is $\hat{x}_t^{data} = \frac{x_t - x}{x}$, while the employment is measured as deviation around the mean, that is $\hat{E}_t^{data} = \frac{E_t - E}{E}$. Furthermore, in order to align the data with the model-based definitions, some additional transformations are made. First, since the model assumes that all real variables are growing at the same rate as output, I match the sample growth rates of private consumption, investment, government consumption, exports, imports and real wage with the sample growth rate of real GDP by removing the remaining growth rate differentials. Second, the model assumes that in steady-state, the interest rates (that is, domestic and foreign interest rate) as well as different measures of inflation (that is, domestic, CPI and foreign inflation) are identical, that is $R = R^*$ and $\pi^d = \pi^c = \pi^*$, respectively. This assumption is clearly rejected by the data. To circumvent this issue, I demean all these time series before the model estimation and add the sample mean of domestic interest rate to the foreign interest

[18] A detailed description of the data used in the estimation together with their sources is provided in Appendix E. Additionally, the data are plotted in Appendix I.

[19] I assume that the employment variable ($\hat{E}_t$) is related to the hours worked variable ($\hat{H}_t$) by an auxiliary equation (expressed as a percentage deviation from the steady state) (Adolfson et al., 2007):

$$\Delta \hat{E}_t = \frac{\beta}{1+\beta}\mathbb{E}_t \Delta \hat{E}_{t+1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{(1+\beta)\xi_e}\left(\hat{H}_t - \hat{E}_t\right).$$

The Calvo parameter, ξ_e, representing the fraction of firms that in any period is able to adjust employment to its desired total labour input, is estimated.

rate and the sample mean of domestic inflation to the CPI and foreign inflation, so that the data match the model assumptions. All variables (except the nominal interest rates) are seasonally adjusted and adjusted by working days. The vector of observable variables, $\tilde{Y}_t$, is then given by:

$$\begin{aligned}\tilde{Y}_t = \Big[\Delta \ln P_t^{d,data} \quad & \Delta \ln \left(W_t/P_t^d\right)^{data} \quad \Delta \ln \tilde{C}_t^{data} \quad \Delta \ln \tilde{I}_t^{data} \quad \hat{x}_t^{data} \dots \\ & R_t^{data} \quad \hat{E}_t^{data} \quad \Delta \ln Y_t^{data} \quad \Delta \ln \tilde{X}_t^{data} \quad \Delta \ln \tilde{M}_t^{data} \dots \\ & \Delta \ln G_t^{data} \quad \Delta \ln P_t^{c,data} \quad \Delta \ln Y_t^{*,data} \quad \Delta \ln P_t^{*,data} \quad R_t^{*,data}\Big]',\end{aligned} \tag{40}$$

where Δ is the first difference operator. The corresponding measurement equation that matches observed data with model's variables is:

$$\tilde{Y}_t = \begin{bmatrix} \Delta \ln P_t^{d,data} \\ \Delta \ln \left(W_t/P_t^d\right)^{data} \\ \Delta \ln \tilde{C}_t^{data} \\ \Delta \ln \tilde{I}_t^{data} \\ \hat{x}_t^{data} \\ R_t^{data} \\ \hat{E}_t^{data} \\ \Delta \ln Y_t^{data} \\ \Delta \ln \tilde{X}_t^{data} \\ \Delta \ln \tilde{M}_t^{data} \\ \Delta \ln G_t^{data} \\ \Delta \ln P_t^{c,data} \\ \Delta \ln Y_t^{*,data} \\ \Delta \ln P_t^{*,data} \\ R_t^{*,data} \end{bmatrix} = \begin{bmatrix} \left(\pi^d - 1\right) \\ \ln \mu_z \\ \ln \mu_z \\ \ln \mu_z \\ 0 \\ 4R\left(R-1\right) \\ 0 \\ \ln \mu_z \\ \ln \mu_z \\ \ln \mu_z \\ \ln \mu_z \\ \left(\pi^d - 1\right) \\ \ln \mu_z \\ \left(\pi^d - 1\right) \\ 4R\left(R-1\right) \end{bmatrix} + \begin{bmatrix} \hat{\pi}_t^d \\ \Delta\hat{\bar{w}}_t + \hat{\mu}_{z,t} \\ \Delta\hat{\tilde{c}}_t + \hat{\mu}_{z,t} \\ \Delta\hat{\tilde{i}}_t + \hat{\mu}_{z,t} \\ \hat{x}_t \\ 4R\hat{R}_t \\ \hat{E}_t \\ \Delta\hat{y}_t + \hat{\mu}_{z,t} \\ \Delta\hat{\tilde{x}}_t + \hat{\mu}_{z,t} \\ \Delta\hat{\tilde{m}}_t + \hat{\mu}_{z,t} \\ \Delta\hat{g}_t + \hat{\mu}_{z,t} \\ \hat{\pi}_t^c \\ \Delta\hat{y}_t^* + \Delta\hat{\tilde{z}}_t^* + \hat{\mu}_{z,t} \\ \hat{\pi}_t^* \\ 4R\hat{R}_t^* \end{bmatrix} + \begin{bmatrix} \varepsilon_{\pi^d,t}^{me} \\ \varepsilon_{\bar{w},t}^{me} \\ \varepsilon_{\tilde{c},t}^{me} \\ \varepsilon_{\tilde{i},t}^{me} \\ \varepsilon_{x,t}^{me} \\ \varepsilon_{R,t}^{me} \\ \varepsilon_{E,t}^{me} \\ \varepsilon_{y,t}^{me} \\ \varepsilon_{\tilde{x},t}^{me} \\ \varepsilon_{\tilde{m},t}^{me} \\ \varepsilon_{g,t}^{me} \\ \varepsilon_{\pi^c,t}^{me} \\ \varepsilon_{y^*,t}^{me} \\ \varepsilon_{\pi^*,t}^{me} \\ \varepsilon_{R^*,t}^{me} \end{bmatrix}, \tag{41}$$

where $\varepsilon_{i,t}^{me}$ denotes the measurement error for the respective variable. The standard deviation of specific measurement error is calibrated at 10 % of the standard deviation of the corresponding observed domestic variables, while the measurement errors for the foreign variables are set to 0, as in Adolfson et al. (2007).

1.3.3 Estimation methodology

Structural parameters of the model are either calibrated or estimated. The values for the parameters that are calibrated (and thus kept fixed throughout the estimation) are chosen in accordance with the practice in the literature calibrating small open-economy models. Their values are discussed in Subsection 2.1. All remaining parameters are estimated with a Bayesian estimation method, which has become a standard econometric technique for estimating DSGE models.[20] In the following, I briefly describe the main features of the method. The key idea of the Bayesian estimation method[21] is that it combines the prior belief of the parameters with empirical data to

[20] All estimates are performed using Dynare version 4.4.3 in Matlab R2012b.

[21] A detailed explanation of the estimation method can be found in An & Schorfheide (2007), Adolfson et al. (2007), Canova (2007), Fernández-Villaverde (2010) and Smets & Wouters (2003, 2007) among many others. The reader is also referred to Dynare Manual for additional explanation of the estimation method.

form the posterior distributions of the parameters. The posterior distributions are obtained by using the Bayes theorem:

$$p\left(\theta|\tilde{Y}_t\right) = \frac{p\left(\tilde{Y}_t|\theta\right) p\left(\theta\right)}{p\left(\tilde{Y}_t\right)}, \tag{42}$$

where θ is a vector of the parameters to estimate, $p\left(\theta|\tilde{Y}_t\right)$ is the density of the parameters conditional on data (the posterior), $p\left(\tilde{Y}_t|\theta\right)$ is the density of the data conditional on the parameters (the likelihood), $p\left(\theta\right)$ is the unconditional density of the parameters (the prior) and $p\left(\tilde{Y}_t\right)$ is the marginal density of the data.[22] Given that the marginal density of the data is a constant term or equal for any parameter, equation (42) can be rewritten as:

$$p\left(\theta|\tilde{Y}_t\right) \propto p\left(\tilde{Y}_t|\theta\right) p\left(\theta\right) \equiv \mathcal{K}\left(\theta|\tilde{Y}_t\right), \tag{43}$$

where $\mathcal{K}\left(\theta|\tilde{Y}_t\right)$ is the posterior kernel. Taking logs of (43), I get:

$$\ln \mathcal{K}\left(\theta|\tilde{Y}_t\right) = \ln p\left(\tilde{Y}_t|\theta\right) + \ln p\left(\theta\right) = \ln \mathcal{L}\left(\tilde{Y}_t|\theta\right) + \ln p\left(\theta\right). \tag{44}$$

Before the estimation can begin, I need to specify the priors for the parameters to be estimated and evaluate the likelihood function of the observed data. The choice of priors is discussed in Subsection 1.3.5. The likelihood function of the observed data is evaluated by generating forecasts from the state-space system, (37) and (38), with the use of the Kalman filter. Conceptually, the Kalman filter consists of calculating the sequence $\left\{\xi_{t+1|t}\right\}_{t=1}^{T}$ and $\left\{\Sigma_{t+1|t}^{\xi}\right\}_{t=1}^{T}$, where $\xi_{t+1|t}$ denotes the optimal forecast of ξ_{t+1} based on observation of $\mathbf{y}_t \equiv \left(\tilde{Y}_t', \tilde{Y}_{t-1}', \tilde{Y}_{t-2}', \ldots, \tilde{Y}_1', x_t', x_{t-1}', x_{t-2}', \ldots, x_1'\right)'$ and $\Sigma_{t+1|t}^{\xi}$ denotes the mean squared error of this forecast. The algorithm works forward in time and is conducted as follows:[23] For $t = 1$, the algorithm needs to be provided with initial values for a one-step ahead forecast of time t states, $\xi_{t|t-1}$, and respective forecast error variance-covariance matrix, $\Sigma_{t|t-1}^{\xi}$. Based on this a one-step ahead forecast of time t data, $\tilde{Y}_{t|t-1}$ and respective variance-covariance matrix, $\Sigma_{t|t-1}^{\tilde{Y}}$ are computed. The algorithm then updates the forecasts of time t states, $\xi_{t|t}$, and respective variance-covariance matrix, $\Sigma_{t|t}^{\xi}$. The final step is to compute a one-step ahead forecast of time $t+1$ states, $\xi_{t+1|t}$, and a respective variance-covariance matrix, $\Sigma_{t+1|t}^{\xi}$. These steps are iterated for $t = 2, 3, 4, \ldots, T$. The log-likelihood function (based on the data up to time t) can be written

[22] It is defined as:

$$p\left(\tilde{Y}_t\right) = \int_{\Theta} p\left(\theta, \tilde{Y}_t\right) \mathrm{d}\theta,$$

where $p\left(\theta, \tilde{Y}_t\right)$ denotes the joint density of the parameters and the data.

[23] The presentation here follows Hamilton (1994).

as follows (Hamilton, 1994):

$$\sum_{t=1}^{T} \ln \mathcal{L}\left(\tilde{Y}_t|x_t, \mathbf{y}_{t-1}, F, A', H', Q, R\right)$$
$$= -\sum_{t=1}^{T}\left[\frac{n}{2}\log 2\pi + \frac{1}{2}\log|\Sigma_{t|t-1}^{\tilde{Y}}| + \frac{1}{2}\sum_{t=1}^{T}\left(\tilde{Y}_t - \tilde{Y}_{t|t-1}\right)'\left(\Sigma_{t|t-1}^{\tilde{Y}}\right)^{-1}\left(\tilde{Y}_t - \tilde{Y}_{t|t-1}\right)\right]. \tag{45}$$

Finally, the posterior distribution is obtained in two steps: first, by maximizing the log posterior density with respect to θ, the posterior mode θ^m and an approximate covariance matrix, based on the inverse Hessian matrix evaluated at the posterior mode, $\Sigma_{\theta^m} = H\left(\theta^m|\tilde{Y}\right)^{-1}$, is obtained and second, the posterior distribution is simulated by using the Monte-Carlo Markov-Chain (MCMC) sampling method, specifically the Metropolis-Hastings (MH) algorithm. The idea behind this algorithm is the following (Mancini Griffoli, 2013): first, the algorithm chooses a starting point (posterior mode), then it draws a candidate value θ^* from an arbitrary candidate (or jumping) distribution:

$$J\left(\theta^*|\theta_{i-1}\right) \sim N\left(\theta_{i-1}, c\Sigma_{\theta^m}\right), \tag{46}$$

where θ_{i-1} is the last accepted draw, Σ_{θ^m} denotes the inverse of the Hessian computed at the posterior mode, and c is the scale factor, which is chosen to ensure an appropriate acceptance rate. In the next step, the algorithm computes the acceptance ratio:

$$\alpha = \min\left[\frac{\mathcal{K}\left(\theta^*|\tilde{Y}_t\right)}{\mathcal{K}\left(\theta_{i-1}|\tilde{Y}_t\right)}, 1\right]. \tag{47}$$

The algorithm then accepts or discards the proposal θ^* according to the following rule:

$$\theta_i = \begin{cases} \theta^* & \text{with probability } \alpha \\ \theta_{i-1} & \text{otherwise} \end{cases}.$$

If the parameter value is accepted, the mean of the distribution is updated with the new draw θ_i. These algorithm steps are repeated many times to simulate the posterior distribution.

1.3.4 Calibrated parameters

In this section, I present the calibrated parameters of the model.[24] Their values are taken mainly from Adolfson et al. (2007) unless otherwise stated. The discount factor, β, is fixed to 0.993, implying a steady-state interest rate of 11 % (annualy),[25] which matches the average interest rate in the sample period. The share of capital in production, α, is calibrated to 0.30. The depreciation rate of capital, δ, is set to 0.013. I calibrate the capital utilization cost parameter, σ_a, to 10^6. The elasticity of substitution between domestic and foreign goods, η_c, is calibrated to 5. Labour disutility constant, A_L, is calibrated to 7.5. As in Christiano et al. (2005), I set the

[24]It is important to note that a time period is taken to be a quarter.

[25]This follows from the first order condition of the households' bond holdings, $R = \frac{\pi\mu_z - \tau^k\beta}{(1-\tau^k)\beta}$.

labour supply elasticity, σ_L, to 1, and the wage mark-up, λ_w, to 1.05. The steady state mark-ups are calibrated at: 1.222 in the domestic goods market (λ^d), 1.633 in the imported consumption goods market ($\lambda_{m,c}$) and 1.275 in the imported investment goods market ($\lambda^{m,i}$). The steady state foreign terms of trade, γ^f, is calibrated to 1. The rest of the parameters, as well as the steady state relationships, are calibrated using the averages of Slovenian data for the period 1995Q1-2014Q4. The shares of imports in consumption and investment, ω_c and ω_i, are set to 0.67 and 0.40, respectively. The steady state rate of transfers to households, τ^{tr}, is calibrated to 0.50. The ratios of government expenditures ($\frac{gex}{y}$), taxes ($\frac{t}{y}$), government consumption ($\frac{g}{y}$), and debt services ($\frac{r}{y}$) in GDP are 0.37, 0.36, 0.19, and 0.02, respectively. Further, the share of government consumption, social transfers and debt services in total government expenditures, $\frac{g}{gex}$, $\frac{tr}{gex}$ and $\frac{r}{gex}$, are set to 0.51, 0.44 and 0.05, respectively. The target value of debt-to-GDP ratio, b^*_y, is assumed to be 240 % in the steady state, which is consistent with the reference value of public debt established by the Maastricht Treaty, which equals 60 % of yearly output. The steady state quarterly gross inflation rate, π^d, is equal to 1.01. Finally, the average effective tax rates on consumption, labour income and capital income, τ^c, τ^y and τ^k, amount to 0.17, 0.48 and 0.22, respectively. An overview of the calibrated parameters is found in Table (1), while Table (2) provides an overview of the steady state relationships.

Table 1: *Calibrated parameters of the model*

Parameter	Description	Calibrated value
β	Households' discount factor	0.993
α	Capital share in production	0.30
η_c	Substitution elasticity between C_t^d and C_t^m	5
σ_a	Capital utilization cost parameter	10^6
A_L	Labour disutility constant	0.3776
σ_L	Labour supply elasticity	1
δ	Depreciation rate of physical capital	0.013
λ_w	Wage mark-up	1.05
λ^d	Mark-up in the domestic goods market	1.168
$\lambda^{m,c}$	Mark-up in the imported consumption goods market	1.619
$\lambda^{m,i}$	Mark-up in the imported investment goods market	1.226
ω_i	Share of imports in investment	0.40
ω_c	Share of imports in consumption	0.67
τ_c	Consumption tax rate	0.114
τ_y	Labour income tax rate	0.48
τ_k	Capital tax rate	0.22
τ^{tr}	Rate of transfers to households	0.50

Source: Own work.

1.3.5 Prior distributions of the estimated parameters

Before the Bayesian estimation method starts, the prior distributions of the estimated parameters need to be specified. As the name suggests, prior distribution describes the available information

Table 2: *Steady state relationships*

Parameter	Description	Value
π^d	Steady state quarterly gross inflation rate	1.01
$\frac{gex}{y}$	Share of government expenditures in GDP	0.37
$\frac{t}{y}$	Share of taxes in GDP	0.36
$\frac{g}{y}$	Share of government consumption in GDP	0.19
$\frac{g}{gex}$	Share of government consumption in government expenditures	0.51
$\frac{r}{y}$	Share of debt services in GDP	0.02
$\frac{r}{gex}$	Share of debt services in government expenditures	0.05
$\frac{tr}{gex}$	Share of social transfers in government expenditures	0.44
b_y^*	Target value of debt-to-GDP ratio	2.4

Source: Own work.

about the parameters prior to observing the data used in the estimation. The observed data is then used to update the prior, through the Bayes theorem, to the posterior distribution of the model's parameters. In specifying the prior distributions I mainly rely on choices from Adolfson et al. (2007).

Throughout the analysis I use four main distributions: beta distribution, inverse gamma distribution, normal distribution and gamma distribution. For the parameters bounded between 0 and 1 I choose beta distribution. Parameters belonging to this group are nominal stickiness parameters ξ, indexation parameters κ, the habit persistence b and the persistence parameters of the shock processes ρ. I set the mean of prior distributions for the price stickiness parameters to 0.5 with standard deviation 0.2, while the mean for the indexation parameters is set to 0.4 with standard deviation 0.1. However, there are three exceptions. For the Calvo parameter for domestic firms I set the prior mean to 0.85 with a standard deviation of 0.1, while for the Calvo parameter for exporting firms I choose a prior mean equal to 0.75 with a standard deviation of 0.1. For the wage indexation parameter I impose a prior mean of 0.5 with a standard deviation of 0.2. The prior on habit persistence has a mean of 0.65 and a standard deviation of 0.2. With the exception of the shocks to the unit-root technology, stationary technology and government consumption, I set the prior means of the persistence parameters for the structural shocks equal to 0.5 with a standard deviation of 0.2. For the unit-root technology, stationary technology and government consumption shocks I choose a mean of 0.6 and a standard deviation of 0.2.

I use inverse gamma distribution to describe priors about the parameters that are assumed to be positive. These parameters are the standard deviations of shocks and the substitution elasticities between goods, η. I set the prior mean of the substitution elasticity between domestic and foreign investment goods, η_i, equal to 0.8, while the prior mean of the substitution elasticity among goods in the foreign economy, η_f, is set to 1.5. Continuing with the standard deviations of shocks[26], I set the standard deviation of the stationary technology shock, σ_ϵ, to 0.007, and the

[26]In order to decrease the degree of non-linearity when estimating the model, the mark-up shocks in the Phillips curves, as well as the investment-specific technology shock, the labour supply shock and the consumption preference shock enter into the equations in an additive way.

standard deviation of the unit-root technology shock, σ_{μ_z}, is assumed to be 0.002, which is the value used by Altig et al. (2011). The size of the risk premium shock, $\sigma_{\tilde{\phi}}$, and the prior on the risk premium parameter related to net foreign assets, $\tilde{\phi}$, are set to 0.0005 and 0.045, respectively. Based on the residuals from a first-order autoregression of the series obtained when substracting the HP-trend in domestic output from the HP-trend in foreign output, I set the size of the asymmetric technology shock, $\sigma_{\tilde{z}^*}$, to 0.003. The consumption preference, labour supply and investment-specific technology shocks, σ_{ζ_c}, σ_{ζ_h} and σ_{Υ}, respectively, are assumed to have the prior mean of 0.002, which is similar to Adolfson et al. (2007). Since I have little information about the properties of these shocks, I choose very loose priors with infinite variances. Regarding the foreign shocks, there are three standard deviations of shocks which need to be specified, namely the standard deviation of the foreign output shock, foreign inflation shock and foreign interest rate shock. I fix their values at the standard deviations of residuals obtained from a pre-estimated foreign VAR model. The standard deviation for the foreign output shock, σ_{y^*}, is, therefore, set to 0.004, the foreign inflation shock, σ_{π^*}, is assumed to have a standard deviation of 0.002, while the standard deviation for the foreign interest rate shock, σ_{R^*}, is set to 0.003.

Finally, turning to the parameters of the fiscal rule, the prior on the persistence parameter (ρ_g) follows a beta distribution with a mean of 0.6 and a standard deviation of 0.2. The priors on the feedback coefficients are assumed to be gamma distributed. I set their values as follows: the prior mean of the feedback coefficient on inflation (ϕ_π) and output gap (ϕ_y) is set to 0.25 with a standard deviation of 0.15, while the prior on the feedback coefficient on public debt (ϕ_b) and government deficit (ϕ_d) is somewhat lower and has a mean equal to 0.05 and a standard deviation of 0.01. For the steady state quarterly gross growth rate, μ_z, I choose normal distribution with prior mean centred around 1.006, implying an annual growth rate of about 2.4 %.

1.4 Estimation results and evaluation

In this section, I present and evaluate the estimation results.

1.4.1 Posterior distributions of the estimated parameters

In total I estimated 50 parameters: 17 friction parameters, 5 policy parameters and 28 shock processes parameters. The posterior mode and an approximate covariance matrix, based on the inverse Hessian matrix evaluated at the mode, have been computed by using a standard numerical optimisation routine, namely Christopher Sims' optimizer csminwel, on the log posterior density. After having optimized the log posterior density, the draws from the posterior distribution have been obtained by simulating two parallel Markov chains of 300,000 draws of the Metropolis-Hastings algorithm, ignoring the first 50 % of draws as burn-in. The average acceptance rate is roughly 32 % across the two Metropolis-Hastings blocks used.

After the estimation, I performed several diagnostic tests to assess the quality of the estimated model. More precisely, I (i) looked at the quality of the posterior kernel optimization, (ii) assessed the convergence of the Markov chains by using both the univariate convergence diagnostics proposed by Brooks & Gelman (1998) as well as the multivariate convergence diagnostics (see Appendix H), and (iii) compared the plots of the prior and posterior distributions. This latter diagnostic can be found in Appendix G. To have sensible estimates, the patterns of the prior and posterior distributions should be reasonably distinct. If the posterior looks like the prior, either the prior is a very accurate reflection of the information in the data or, more usually, the parameter under consideration is only weakly identified and the data does not provide much information to update the prior (Canova, 2007). On the other hand, if the prior and posterior distribution are far away from each other, this typically indicates that there is a disagreement between the information provided by the data and the prior knowledge about the true parameter value. In addition, the posterior distribution should be approximately normal in shape, which is in line with the asymptotic properties of Bayesian estimation, and the mode should be in the center of the posterior distribution.

As seen in these plots, the most of the estimated parameters are well identified as their posterior distribution is reasonably different from the prior distribution. Moreover, for the majority of the parameters, the variance of the posterior is lower compared to the prior distribution, indicating that data are quite informative. The mode check plots (not presented here) indicate that the optimization procedure was able to precisely find a robust maximum for the posterior kernel. Finally, both univariate and multivariate convergence graphs (also not presented here) confirm that the parameters are generally characterized by good convergence.[27]

The estimation results are summarized in Table (3) and (4), which provide prior distributions, posterior estimations and 90 % confidence intervals of the estimated parameters and shocks. Let me now briefly discuss the estimation results. Beginning with the Calvo price stickiness parameters, I find that the domestic price stickiness parameter ξ_d is estimated at 0.90, which implies the average duration of prices of about 10 quarters.[28] The values for the other sectors ($\xi_{m,c}$, $\xi_{m,i}$ and ξ_x) are estimated as follows: the estimated price stickiness parameter for the imported consumption, $\xi_{m,c}$, is equal to 0.71, suggesting that prices remain on average unchanged for 3 quarters. Furthermore, the posterior mean of the price stickiness parameter for the imported investment, $\xi_{m,i}$, is estimated at 0.52. The average duration of prices in this sector is therefore 2 quarters. The export price stickiness parameter, ξ_x, in turn, is estimated at 0.87, corresponding to an average price duration of 7 quarters. The posterior mean of the Calvo wage stickiness parameter, ξ_w, is nearly 0.56. This value implies that wages are reset as frequent as twice a year. Considering next the indexation parameters, I find that the posterior mean of the degree of wage indexation, κ_w, is estimated at 0.60, while the remaining indexation parameters (κ_d, $\kappa_{m,c}$, $\kappa_{m,i}$, κ_x) are estimated at a lower value. The posterior mean of the habit persistence parameter in consumption, b, is estimated at 0.94. Furthermore, the estimates suggest the substitution elasticity between domestic and foreign investment goods, η_i, of around 0.29, while the posterior mean for the substitution elasticity among goods in the foreign economy, η_f, is estimated at 1.37. The investment adjustment cost parameter, $\tilde{S}''$, is estimated to be equal to 8.65. The posterior mean of the risk premium parameter related to net foreign assets, $\tilde{\phi}_a$, is 0.03.

[27]Due to space limitations these graphs are not presented here, but they are available from the author upon request.

[28]Average duration of prices comes from $\frac{1}{1-\xi_d}$.

Regarding the parameters in the fiscal policy rule, I find that the feedback coefficient of government consumption to inflation, ϕ_π, is estimated at 0.22, the estimated feedback coefficient of output gap, ϕ_y, is 0.08, while the estimated feedback coefficients of public debt and government deficit, ϕ_b and ϕ_d, are equal to 0.06 and 0.05, respectively. It is worth noting that the latter two parameters are driven by a prior. This can be explained by the fact that I do not use the data on public debt and government deficit in the estimation. The persistence parameter in the fiscal rule, ρ_g, is estimated to be 0.50, which indicates a moderate degree of persistence in government consumption.

Finally, I consider the parameters associated with the persistence and volatility of shock processes. I find that the autoregressive parameters are estimated to lie between 0.22 for the consumption preference shock and 0.96 for the unit-root technology shock. In general, the level of persistence of stochastic processes is not very high, indicating that the model contains a sufficiently persistent endogenous propagation mechanism. Turning to the estimated standard deviations of shocks, I find that the most volatile are the imported investment mark-up shocks and the investment-specific technology shock, with standard deviations of 0.3345 and 0.0309, respectively, while the least volatile is the unit-root technology shock with a standard deviation equal to 0.0013.

Table 3: *Prior and posterior distribution of structural parameters*

		Prior distribution			Posterior distribution				
Description	Parameter	Type	Mean	Std. Dev./Df	Mode	Std. Dev.	Mean	5 %	95 %
Friction parameters									
Calvo wages	ξ_w	Beta	0.500	0.200	0.5775	0.0881	0.5568	0.4173	0.6918
Calvo domestic prices	ξ_d	Beta	0.850	0.100	0.9044	0.0206	0.9018	0.8639	0.9365
Calvo import consumption prices	$\xi_{m,c}$	Beta	0.500	0.200	0.7569	0.0957	0.7051	0.5352	0.8673
Calvo import investment prices	$\xi_{m,i}$	Beta	0.500	0.200	0.6293	0.1099	0.5195	0.2910	0.7509
Calvo export prices	ξ_x	Beta	0.750	0.100	0.8954	0.0439	0.8655	0.7689	0.9702
Calvo employment	ξ_e	Beta	0.500	0.200	0.8112	0.0319	0.8232	0.7762	0.8757
Indexation wages	κ_w	Beta	0.500	0.200	0.5927	0.1770	0.6016	0.3491	0.8291
Indexation domestic prices	κ_d	Beta	0.400	0.100	0.2013	0.0643	0.2181	0.1064	0.3172
Indexation import consumption prices	$\kappa_{m,c}$	Beta	0.400	0.100	0.3379	0.1110	0.3510	0.1951	0.5056
Indexation import investment prices	$\kappa_{m,i}$	Beta	0.400	0.100	0.3250	0.0957	0.3349	0.1814	0.4848
Indexation export prices	κ_x	Beta	0.400	0.100	0.3293	0.0996	0.3309	0.1786	0.4764
Investment adjustment cost	$\tilde{S}^*$	Normal	7.694	1.500	8.6319	1.2547	8.6526	6.5778	10.6581
Habit formation	b	Beta	0.650	0.200	0.9442	0.0214	0.9413	0.9081	0.9761
Substitution elasticity investment	η_i	Inv. Gamma	0.800	inf	0.2860	0.0552	0.2925	0.2001	0.3847
Substitution elasticity foreign	η_f	Inv. Gamma	1.500	2	1.1934	0.4019	1.3696	0.6160	2.1375
Technology growth	μ_z	Beta	1.006	0.005	1.0061	0.0005	1.0061	1.0054	1.0068
Risk premium	$\tilde{\phi}_a$	Beta	0.045	0.02	0.0234	0.0103	0.0296	0.0115	0.0460
Policy parameters									
Policy rule: lagged gov. consumption	ρ_g	Beta	0.600	0.200	0.5149	0.1585	0.4987	0.3314	0.6619
Policy rule: inflation	ϕ_π	Gamma	0.25	0.15	0.1900	0.0990	0.2234	0.0623	0.3765
Policy rule: output gap	ϕ_y	Gamma	0.25	0.15	0.0649	0.0491	0.0834	0.0148	0.1451
Policy rule: public debt	ϕ_b	Gamma	0.05	0.01	0.0508	0.0160	0.0553	0.0381	0.0716
Policy rule: gov. deficit	ϕ_{def}	Gamma	0.05	0.01	0.0495	0.0101	0.0514	0.0339	0.0674

Table 4: *Prior and posterior distribution of shock processes*

		Prior distribution			Posterior distribution				
Description	Parameter	Type	Mean	Std. Dev./Df	Mode	Std. Dev.	Mean	5 %	95 %
Persistence parameters									
Unit-root technology shock	ρ_{μ_z}	Beta	0.600	0.200	0.9707	0.0167	0.9577	0.9272	0.9899
Stationary technology shock	ρ_{ϵ}	Beta	0.600	0.200	0.8697	0.1096	0.7887	0.6071	0.9613
Investment-specific technology shock	ρ_{Υ}	Beta	0.500	0.200	0.2872	0.1381	0.2775	0.0823	0.4677
Asymmetric technology shock	$\rho_{\tilde{z}^*}$	Beta	0.500	0.200	0.9872	0.0091	0.9822	0.9678	0.9971
Consumption preference shock	ρ_{ζ_c}	Beta	0.500	0.200	0.1938	0.0979	0.2228	0.0773	0.3700
Labour supply shock	ρ_{ζ_h}	Beta	0.500	0.200	0.5307	0.3261	0.5435	0.2473	0.8126
Risk premium shock	$\rho_{\tilde{\phi}}$	Beta	0.500	0.200	0.9329	0.0153	0.9317	0.9076	0.9577
Domestic mark-up shock	ρ_{λ_d}	Beta	0.500	0.200	0.4599	0.0988	0.4742	0.3051	0.6394
Import consumption mark-up shock	$\rho_{\lambda_{m,c}}$	Beta	0.500	0.200	0.4727	0.2155	0.5425	0.2412	0.8520
Import investment mark-up shock	$\rho_{\lambda_{m,i}}$	Beta	0.500	0.200	0.1670	0.1219	0.3121	0.0500	0.5801
Export mark-up shock	ρ_{λ_x}	Beta	0.500	0.200	0.2893	0.1458	0.3566	0.0859	0.6103
Rate of transfers shock	$\rho_{\tau^{tr}}$	Beta	0.500	0.200	0.6550	0.1105	0.5941	0.3635	0.8286
Standard deviations									
Unit-root technology shock	σ_{μ_z}	Inv. Gamma	0.002	inf	0.0011	0.0002	0.0013	0.0008	0.0017
Stationary technology shock	σ_{ϵ}	Inv. Gamma	0.007	inf	0.0126	0.0056	0.0210	0.0071	0.0380
Investment-specific technology shock	σ_{Υ}	Inv. Gamma	0.002	inf	0.0304	0.0040	0.0309	0.0246	0.0367
Asymmetric technology shock	$\sigma_{\tilde{z}^*}$	Inv. Gamma	0.003	inf	0.0037	0.0005	0.0038	0.0030	0.0047
Consumption preference shock	σ_{ζ_c}	Inv. Gamma	0.002	inf	0.0044	0.0006	0.0044	0.0035	0.0054
Labour supply shock	σ_{ζ_h}	Inv. Gamma	0.002	inf	0.0010	0.0005	0.0015	0.0006	0.0023
Risk premium shock	$\sigma_{\tilde{\phi}}$	Inv. Gamma	0.0005	inf	0.0030	0.0003	0.0032	0.0026	0.0036
Domestic mark-up shock	σ_{λ_d}	Inv. Gamma	0.003	inf	0.0024	0.0003	0.0024	0.0018	0.0030
Import consumption mark-up shock	$\sigma_{\lambda_{m,c}}$	Inv. Gamma	0.003	inf	0.0026	0.0004	0.0028	0.0019	0.0037
Import investment mark-up shock	$\sigma_{\lambda_{m,i}}$	Inv. Gamma	0.003	inf	0.2533	0.0756	0.3345	0.1470	0.5169
Export mark-up shock	σ_{λ_x}	Inv. Gamma	0.003	inf	0.0112	0.0043	0.0113	0.0044	0.0184
Government consumption shock	σ_g	Inv. Gamma	0.002	inf	0.0049	0.0006	0.0050	0.0041	0.0058

Table continued on next page

Description	Parameter	Prior distribution			Posterior distribution				
		Type	Mean	Std. Dev./Df	Mode	Std. Dev.	Mean	5 %	95 %
Rate of transfers shock	$\sigma_{\tau^{tr}}$	Inv. Gamma	0.002	inf	0.0018	0.0005	0.0016	0.0007	0.0023

Source: Own work.

1.4.2 Assessing the empirical performance of the model

After having presented and evaluated the estimation results, I now proceed with the assessment of the empirical performance of the estimated model. This is done in three directions. First, I evaluate the absolute (in-sample) fit of the model. Second, I compare the unconditional second moments in the estimated DSGE model with those based on the actual data. Finally, I look at the smoothed estimates of the innovation component of structural shocks.

In Figure (I.1) in Appendix I, I first plot the actual series used in the estimation along with filtered variables obtained by the one-sided Kalman filter for each of the fifteen observable variables. The thin red line depicts the mean estimate of the one step ahead forecast of the endogenous variables (best guess for the endogenous variables at time $t + 1$ given information up to the current observations t), derived from the Kalman filter, whereas the thick black line represents the actual data (Pfeifer, 2014b). As it can be seen from the sub-plots, the in-sample fit of the model is satisfactory in most of the cases since the model predictions closely follow the path of the observed historical data. However, the model is not good at capturing government consumption.

The common practice in the DSGE literature is to analyse how well the model's moments match those from the actual data. As a next step I therefore compare the second moments in the data (for the period 1995Q2-2014Q4) with those in the model (calculated at the posterior mean). The results are presented in Table (5). The first column presents the standard deviations of the selected observed variables and their counterparts implied by the estimated model. The second column reports the first order autocorrelation coefficients. The last two columns show correlations with GDP growth rates and domestic inflation, respectively. Several results are worth highlighting here. First, the model is able to replicate quite well the volatilities of some observables, in particular those of the growth rate of GDP and government consumption, but generates much high volatile consumption growth rates as compared to the data. Consumption growth in the model is three times more volatile than in the data. Furthermore, I can observe that the model replicates quite closely the positive correlation of investment and government consumption growth rates with GDP growth rates. The correlation between investment and GDP growth rates is 0.67 in the model, while it is 0.77 in the data. These numbers are respectively 0.09 and 0.14 for the correlation of government consumption. On the other hand, the correlation of imports and exports seems to be underestimated by the model (0.77 in the data and 0.40 in the model for imports, 0.70 in the data and 0.41 in the model for exports), while the correlation of consumption is slightly overestimated by the model (0.42 in the data and 0.64 in the model). Furthermore, the model is quite successful in predicting the persistence of the observables, except the persistence of consumption, investment and imports that is over-predicted compared to their empirical counterparts. From the table I can also see that the model is less successful in replicating the observed correlations between the respective variables and inflation.

Finally, Figures (J.1a)-(J.1b) in Appendix J plot the estimated structural shocks of the model. The values plotted are obtained using the two-sided Kalman filter and represent the most likely values for the respective shock in a particular period, whereas the green areas provide the highest posterior density intervals (HPDI) (Pfeifer, 2014b). For the estimates to be sensible, they should be stationary around zero. As can clearly be seen from the figures, the estimates tend to fluctuate around zero over time and look clearly stationary, which gives some positive indication on the statistical validity of the estimated model.

Table 5: *Unconditional second moments in the data (1995Q2-2014Q4) and in the model*

	Standard dev.		Autocorrelation		Corr with $\Delta \ln Y_t$		Corr with $\Delta \ln P_t^d$	
	Data	Model	Data	Model	Data	Model	Data	Model
$\Delta \ln P_t^d$	0.95	0.75	0.62	0.74	0.03	-0.46	1	1
$\Delta \ln \left(W_t/P_t^d\right)$	1.09	1.17	0.49	0.59	0.74	0.46	-0.01	-0.38
$\Delta \ln \tilde{C}_t$	1.51	4.91	-0.09	0.67	0.42	0.64	0.11	-0.75
$\Delta \ln \tilde{I}_t$	7.06	8.28	-0.15	0.35	0.77	0.67	-0.13	-0.22
$\hat{E}_t$	3.17	5.13	0.99	0.99	-0.36	0.02	-0.42	0.03
$\Delta \ln Y_t$	1.18	1.43	0.49	0.47	1	1	0.03	-0.46
$\Delta \ln \tilde{X}_t$	2.80	3.13	0.45	0.50	0.70	0.41	-0.07	-0.05
$\Delta \ln \tilde{M}_t$	3.97	4.34	-0.02	0.30	0.77	0.40	-0.13	-0.05
$\Delta \ln G_t$	0.76	0.78	0.22	0.29	0.14	0.09	0.47	0.14

Notes: Standard deviations are in percent. Values implied by the model are calculated at the posterior mean estimates of the model's parameters.

Source: Own work.

1.5 Application: What structural shocks drive the Slovenian economy?

After having verified the empirical performance of the model, I use the estimated DSGE model to analyse historical contributions of structural shocks to the business cycle developments in the Slovenian economy. In particular, I focus my attention to analyse the main driving forces behind the real GDP growth and its components during the sample period with special focus on the recent recessions. Before proceeding to such analyses, it is useful to discuss the impulse response functions and variance decompositions to understand the reaction and properties of different shocks.

1.5.1 Impulse response analysis

This section briefly discusses the impulse response functions of some selected variables[29] from shocks that appear to be, based on a historical decomposition of the data (discussed in more detail in Subsection 1.5.3), the most important in driving macroeconomic fluctuations in Slovenia. The results are reported in Figures (K.1)-(K.9) in Appendix K, displaying impulse responses up to 20 quarters. These figures portray a Bayesian version of the impulse responses which are presented

[29]Although the model includes 81 endogenous variables, I restrict my attention to key variables only. These variables include the GDP and its main components, domestic inflation, CPI inflation, real wages, employment and real exchange rate.

in terms of mean responses of endogenous variables (solid line) together with the 5 % and 95 % posterior intervals (dashed lines). Notice that all quantities are reported as log deviations from the steady state (i.e. percentage deviations).

I first focus on the impulse responses to a permanent (unit-root) technology shock that captures permanent shifts in total factor productivity (see Figure (K.1)). As can be seen in the figure, this shock induces all variables (except the real exchange rate and private consumption) to rise. After the initial drop, it has also a positive impact on private consumption.

Figure (K.2) plots the impulse responses to a transitory (stationary) technology shock. As expected, this shock has expansionary effects on the economy. When such a shock hits the economy, marginal cost of domestic firms decreases, which reduces domestic inflation and increases domestic output. Since the increase of output outperforms the decrease in inflation, government consumption is decreased by the government. One noticeable observation is that the model predicts negative response for employment. The reason for this is that the model includes various rigidities that restrict the increase in aggregate demand, which further induces a fall in employment as firms have become more productive.

Next, I present the impulse response functions to an investment-specific technology shock (also referred to as a shock to the marginal efficiency of investment), which affects the transformation of investment into physical capital (see Figure (K.3)). A positive realization of this shock is associated with an increase in investment. This induces an increase in aggregate demand and output in the economy. Interestingly, domestic inflation slightly decreases after this shock, while private consumption increases. Further, if I look at the impulse responses of government consumption, I can see that the government reduces its consumption to dampen demand. The expansion in the economy drives up imports, while exports suffer from higher prices caused by increasing domestic marginal costs.

Figure (K.4) refers to the case when the economy is hit by a consumption preference shock. This shock causes an increase in consumption, investment and output. To meet the higher demand, firms increase capital utilisation and employment. Firms therefore face rising marginal costs, and they respond by increasing prices. Higher domestic prices drive up CPI inflation. This, in turn, induces the government to decrease its consumption to counter the expansion in the economy.

Next, I present the impulse responses to a negative labour supply shock (i.e., an increase in the disutility of working, ζ_t^h). The impulse responses are presented in Figure (K.5). This shock leads to a decline in hours worked and to an increase in the real wage. This increase in the real wage leads to an increase in marginal cost and inflation. Through the usual aggregate demand effects, the result is a recession in the economy.

In the following, I discuss the impulse responses to four mark-up shocks. Figure (K.6) depicts the impulse responses to a domestic mark-up shock. As a consequence of this shock, domestic inflation increases. Higher domestic prices lead to a decrease in demand of domestic consumption and investment goods. Consumption demand is also shifted towards imported goods that are cheaper than domestic production. Volumes of imports therefore increase. As a consequence, lower domestic production has a negative impact on both hours worked and wages. Higher domestic prices also negatively affect the competitiveness of exports. All these factors cause a decrease in the GDP growth rate. Government consumption, which follows a fiscal rule, decreases on impact in response to the increase in inflation.

Figures (K.7) and (K.8) contain the impulse response functions to an imported consumption and investment shock, respectively. After the imported consumption shock, the prices of imported consumption goods increase. This leads households to buy fewer of these goods. The increase in imported consumption inflation also drives up CPI inflation. Because imported consumption goods are now more expensive relative to the domestic ones, expenditure switching towards domestic goods works to expand the economy. As domestic firms see marginal costs go up, they increase their prices and domestic inflation increases. This has a negative effect on exports. Nevertheless, output increases because of increased domestic demand. The government therefore reduces demand in the economy by decreasing its consumption.

Figure (K.8) shows impulse response functions to an imported investment mark-up shock. Following this shock, prices of the imported investment goods rise up. As a consequence, the resulting relative price effects induce investment to fall whereas consumption increases. Decrease in demand for imported investment goods causes a reduction in imports. Domestic inflation rises up. Due to higher domestic prices, export decreases. Because of reduced exports, production in the economy falls and thus output decreases. To stimulate the economy, the government increases its consumption.

Finally, in Figure (K.9) I present the dynamics of the economy following an export mark-up shock. After this shock prices of exported goods rise up. This leads to a fall in exports and consequently domestic firms produce less output. Lower production forces firms to reduce demand for labour and capital services, pushing down wages and rental rate of capital. This reduces marginal costs, allowing domestic firms to reduce prices on domestic goods. The fall in domestic inflation also works to reduce CPI inflation. Consequently, this has a positive effect on domestic demand. Since the increase in domestic demand is not sufficient to off-set the fall in exports, output falls. Fiscal policy therefore responds by raising government consumption.

1.5.2 Variance decompositions

In this section, I use the estimated model to decompose the unconditional variances of the observable variables into the contributions of the structural shocks. Although the primary interest of this chapter is to investigate the background of the GDP (and its main components) fluctuations, I also present results for some other macroeconomic aggregates. The results are presented in Table (6), where I report the unconditional variance decomposition analysis (i.e., evaluated at the infinite horizon)[30] computed at the posterior mean for selected observable variables.

[30] In general, Dynare allows for two types of variance decompositions. The first one is the variance decomposition that is obtained under stoch_simul command and is calculated at the calibrated parameter combination, e.g., at the posterior mean (at the average over the parameters), while the second one is the so-called Bayesian variance decomposition, which is the average of the variance decomposition over the parameter draws. Furthermore, Dynare distinguishes between the conditional and unconditional variance decomposition. The first one is at a particular

To facilitate the presentation, I divide the shocks into five categories. The first contains technology shocks: the stationary ($\varepsilon_{\epsilon,t}$), unit-root ($\varepsilon_{\mu_z,t}$), investment-specific ($\varepsilon_{\Upsilon,t}$), and asymmetric technology ($\varepsilon_{\tilde{z}^*,t}$) shocks. The second category includes supply shocks: the labour supply shock ($\varepsilon_{\zeta^h,t}$) and shocks to the mark-ups of the domestic ($\varepsilon_{\lambda^d,t}$), imported consumption ($\varepsilon_{\lambda^{mc},t}$), imported investment ($\varepsilon_{\lambda^{mi},t}$), and export ($\varepsilon_{\lambda^x,t}$) goods. The third category contains the domestic demand shock: the consumption preference shock ($\varepsilon_{\zeta^c,t}$). The fourth category includes foreign shocks: the uncovered interest rate parity ($\varepsilon_{\tilde{\phi},t}$), foreign output ($\varepsilon_{y^*,t}$), foreign inflation ($\varepsilon_{\pi^*,t}$) and foreign interest rate ($\varepsilon_{R^*,t}$) shocks. Finally, I have the fiscal policy shocks: the government spending ($\varepsilon_{g,t}$) and rate of transfers to households ($\varepsilon_{\tau^{tr},t}$) shocks.

It is evident from the table that technology shocks play the most important role in fluctuation of the GDP and investment growth. The results show that roughly 50 % and 80 % of fluctuations in GDP and investment growth rates, respectively, are due to technology shocks. In this context, the most important technology shocks are the investment-specific technology shocks. Among the 50 % (80 %) of fluctuations of GDP (investment) growth rates explained by technology shocks, investment-specific technology shocks account for around 38 % (78 %). Furthermore, I can observe that supply shocks are the main drivers of fluctuations in the domestic inflation, real wages, consumption, exports and imports. More specifically, domestic inflation is mainly driven by domestic mark-up shocks. In my case they account for 41 % of the total variation. Moreover, domestic mark-up and imported consumption mark-up shocks appear to have a leading role in explaining consumption growth fluctuations. They explain about 28 % of total volatility. The shocks most responsible for the variability of real wages are labour supply shocks (34 %). The export mark-up shocks turn out to be the key drivers for the exports, contributing to approximately 91 % of total volatility, while the imported investment mark-up shocks play the most important role in accounting for the variation in imports, explaining about 54 % of total volatility in that variable. Next, the estimates suggest that demand shocks have some importance in the model in the sense that they explain about 15 % of the variance in GDP growth rates, but their contribution to the remaining variables is negligible. Finally, I can observe that foreign and fiscal shocks explain a small fraction of variability in all variables and thus do not play an important role in explaining the Slovenian business cycle.[31]

time horizon, while the second one is at horizon infinity.

[31]The small impact of foreign shocks may be due to the simplified representation of the foreign block, which is modelled as a VAR model.

Table 6: *Variance decompositions (in %) evaluated at the infinite horizon*

Variable	Technology	Supply	Demand	Foreign	Fiscal
$\ln P_t^d$	33.70	57.01	0.27	7.34	0.10
$\Delta\left(\ln W_t/P_t^d\right)$	36.95	60.59	0.19	1.03	0.38
$\Delta \ln \tilde{C}_t$	27.52	66.27	3.45	2.59	0.07
$\Delta \ln \tilde{I}_t$	79.82	16.03	0.24	2.90	0.01
$\hat{E}_t$	60.30	32.25	4.56	2.45	0.06
$\Delta \ln Y_t$	49.60	33.26	14.84	0.98	0.62
$\Delta \ln \tilde{X}_t$	4.13	92.52	0	2.54	0
$\Delta \ln \tilde{M}_t$	41.70	55.11	0.17	2.19	0
$\Delta \ln G_t$	35.88	5.44	0.27	1.62	55.85

Notes: The unconditional variance decomposition is performed at the posterior mean estimates of the model's parameters. Shocks are aggregated as explained in the main text.

Source: Own work.

1.5.3 Historical decompositions

The economic developments in Slovenia in recent years have been characterized by one of the biggest decline in economic growth in the European Union. Since 2008, Slovenia has experienced a double-dip recession. After a significant decline in GDP over the 2008-2009 period, the period of short-lived recovery began, but in the last quarter of 2011 Slovenia again dropped into recession. The question that arises is, what were the main driving forces behind the decline in GDP during the recent recessions? To answer this question, I calculate historical decompositions that allow me to investigate the role of shocks in explaining the movement of observable variables over the sample period. In discussing the results, I focus on four variables: GDP, private consumption, investment, import and export. All variables are in growth rates and expressed in real terms. The historical decomposition of real GDP growth is provided in Figure (1), while the remaining graphs are presented in Appendix L. In all graphs the bold black line represents the estimate of the smoothed observed variables[32] (best guess for the observed variables given all observations) derived from the Kalman smoother, while the coloured bars correspond to the contribution of the respective smoothed shock to the deviation of the smoothed observable variable from its steady state (Pfeifer, 2014b). Bars above the horizontal axis represent positive shock contributions, while bars below the horizontal axis show negative contributions.

Figure (1) decomposes the growth rate of real GDP dynamics over the underlying period. Prior to the crisis, Slovenia was characterized by a very high growth rate of the GDP. During the period 1996-2005, the annual growth rate of real GDP averaged 4 %. The highest growth rate of GDP was achieved in the years 2006-2008, reaching its peak in 2007, when it was 6.7 %. The historical decomposition results show that while domestic mark-up shocks had a positive effect on economic growth in this period, stationary technology and labour supply shocks had

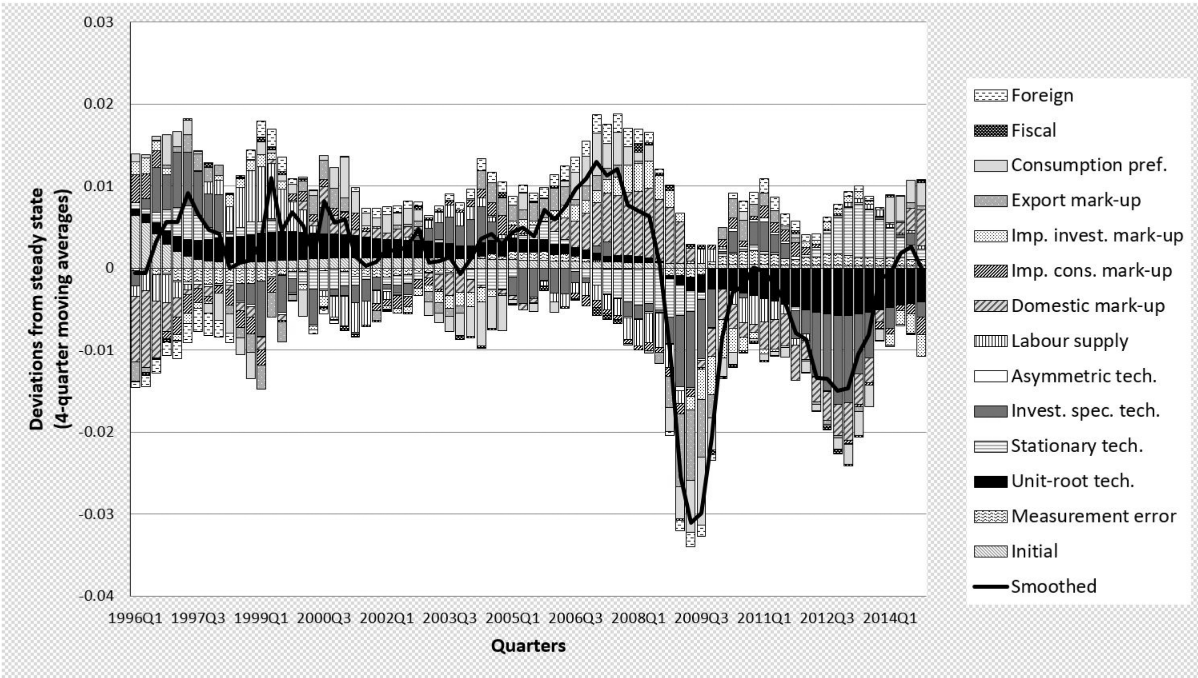
[32] The smoothed series results from the Kalman smoother. They are the best guess of the variables given the information for the whole sample. Given that they are observed, their best guess is the actual value. Hence, there should be no difference unless one assumes they are observed only with measurement error (Pfeifer, 2014b).

a negative one. The intuition behind this result can be explained as follows: During this period, domestic mark-up shocks appear to have contributed significantly to lower inflation, which in turn stimulated the economy. This could be contributed to the entrance of Slovenia to the EMU, since this process was characterized by the efforts aimed to achieve sufficiently low inflation to satisfy the euro adoption, as well as by the convergence of previously high Slovenian interest rates towards lower interest rates in the Euro area. This enabled the Slovenian banks to get access to low interest rate credits from abroad, which were mainly intended for the corporate sector. The competition among banks has further induced a decrease in effective interest rates and thus reduced borrowing costs for a business. At the same time, negative transitory (stationary) technology and labour supply shocks that resulted in lower efficiencies of production and higher wages, caused an upward inflationary pressures, which affected GDP growth negatively.

Since the first quarter of 2008, the GDP growth has experienced persistent declines until reaching the bottom in the first quarter of 2009. In that quarter, the GDP declined by about 5 % relative to the previous quarter. As the model's estimates suggest, this negative dynamics was mainly driven by investment-specific technology, consumption preference and export mark-up shocks. Investment-specific technology shocks to a large extent reflect a drop in foreign and domestic orders, followed by a decline in investment. This effect was further compounded by tougher access to financial resources. Consumption preference and export mark-up shocks also contributed to the slowdown in economic activity in the 2008-2009 period. It is likely that consumption preference shocks reflect the reduction in households' income (in combination with the precautionary saving) while export mark-up shocks could capture the loss of external competitiveness from an increase in wages, reflected in a series of negative labour supply shocks identified right before the crisis. The analysis also points out that fiscal and foreign shocks played a smaller but nevertheless noticeable role in driving the Slovenian business cycle. According to the model, fiscal shocks have contributed positively over the whole pre-crisis period. The positive effect was still visible in the early stages of the crisis, when loose fiscal policy mitigated the economic slowdown, although during the ongoing recession fiscal tightening (as a result of austerity measures adopted to consolidate public finances) was suppressing GDP. However, it should be noted that the impact of fiscal policy shocks was small compared to other shocks, which suggests a relatively minor significance of changes in fiscal policy for cyclical fluctuations in GDP growth. The results regarding the effects of foreign shocks show that the direction of foreign shocks has reversed its course in 2010, from having a negative effect on GDP growth during the period 2008-2010 to having a positive influence by the middle of 2010, where the latter can be attributed to improvements in the economic situation in Slovenia's main trading partners. Moreover, the historical decomposition also suggests that investment-specific technology shocks continued to be the main sources of blocking recovery in more recent years, especially in the years 2012-2013, when Slovenia fell into its second recession, in which GDP declined by about -2 % (quarter-on-quarter) in real terms. This result is obviously connected to banking system problems. Namely, the Slovenian banking system has accumulated a large amount of non-performing bad loans in the last years, resulting in a credit crunch which in turn caused a cutback in corporate investment and impeded economic activity. The model also identifies the important role of permanent (unit-root) technology shocks in explaining the movements of real GDP growth, from having a small but positive impact on GDP growth dynamics in the pre-crisis period to having negative one in recessionary periods, in particular between 2012-2013, and whose negative effects also lasted during the recovery phase. This result could be considered as associated with the lack of productivity-enhancing and other structural reforms in the run-up to the crisis. On the other hand, transitory (stationary) technology shocks has had a positive impact on economic growth, especially from 2013 onwards. This result may be interpreted as resulting from a temporary greater tendency of corporate sector to take restructuring measures in response to the crisis to enhance its production efficiency. If I compare the two recessionary periods, I can observe that in contrast to the first period (2008-2009), when investment-specific technology shocks were accompanied by consumption preference and export mark-up shocks, in the second period (2012-2013), export mark-up shocks made virtually no contribution to the downturn, pointing to a recovery in exports thanks to improving foreign demand, and more importantly, to wage moderation and productivity gains, which translated into considerable competitiveness gains and strong export performance. According to the results obtained, it can also be observed that at the end of the sample period, when the recovery officially began, consumption preference shocks were the main contributors to the pace of economic recovery, presumably due to the increased consumer confidence, resolution of banking system problems, and the improvement in the labour market situation.

Turning now to the main components of GDP, Figure (L.1) in Appendix L shows the historical decomposition of consumption growth. As can be seen from the figure, the movement of consumption growth was affected by a variety of structural shocks. Consistent with the variance decomposition results, the shocks most important for explaining dynamics of consumption growth rates over the sample period were stationary technology shocks, investment-specific technology shocks, domestic mark-up shocks and imported consumption mark-up shocks. Figures (L.2)-(L.3) (see Appendix L) plot the historical decomposition results for investment and imports, respectively. As can be seen from the figures, the investment-specific technology shocks and the imported investment mark-up shocks explained most of the variation in these two variables. Finally, Figure (L.4) (see Appendix L) portrays historical decomposition of the growth rates of exports. As illustrated in the figure, almost all historical variation in exports was due to export mark-up shocks.

Figure 1: *Historical decomposition of GDP growth in terms of the structural shocks*



Notes: The smoothed observed time series is plotted excluding its mean.

Source: Own work.

1.6 Conclusions and policy recommendations

The main purpose of this chapter is to apply the Bayesian method to estimate a medium-scale DSGE model for the Slovenian economy, that is in line with Adolfson et al. (2007) and Masten (2010), and on its basis to investigate the contribution of different structural shocks to the evolution of key macroeconomic variables.

After the estimation, I first describe the estimation results and perform several tests on the quality of the estimation process. Further, I evaluate the model's empirical performance. Overall, the estimation results are satisfactory. The diagnostic tests indicate that the estimation is robust in what concerns the quality of the numerical posterior kernel optimization and the convergence of the MCMC procedure. Furthermore, the majority of the parameters appear to be well identified by the data and the data fit of the model is good. The obtained estimates for the structural parameters of interest are generally in line with the literature and, in most cases, seem to make sense from an economic point of view.

In the last part of the chapter, the empirical importance of various types of structural shocks in explaining macroeconomic fluctuations in the Slovenian economy is studied using impulse responses, variance and shock decompositions. The main findings can be summarized as follows. The variance decomposition results show that the investment-specific technology shock is the major driving force of the growth rates of GDP and investment. Moreover, domestic mark-up shocks are estimated to have a leading role in explaining consumption growth and inflation fluctuations. The labour supply shocks explain the majority of the variance of real wages. The variance of imports growth rates is explained mainly by imported investment mark-up shocks, while the exported mark-up shocks account for most of the variation in exports growth rates. The effect of consumption preference shocks on the economy is estimated to be rather limited, with the largest influence on the GDP and consumption growth rates. Finally, fiscal and foreign shocks are estimated to have a negligible effect in the model.

Last, using historical decompositions, I estimate the individual contributions of each structural shock to the movements in GDP growth rates (and its main components) over the sample period, focusing mainly on the two recessionary periods: 2008-2009 and 2012-2013. The results suggest that investment-specific technology shocks accounted for a significant portion of the drop in output from 2008 onwards. This result accords with a drop in foreign and domestic orders followed by a decline in investment (mostly at the beginning of the crisis), as well as with a significant tightening of credit availability, thereby reducing expenditures on investment, which produced a decrease in the aggregate demand and output. Consumption preference and export mark-up shocks were another important sources that contributed to the slowdown in economic activity, especially in the first recession (2008-2009), most likely reflecting the reduction in households' income (in combination with the precautionary saving) and the fall in exports, mainly due to the deterioration of external competitiveness as wages increased faster than productivity before the crisis years, respectively. A noticeable but smaller impact was also exerted by foreign and fiscal shocks. Furthermore, the results show that permanent (unit-root) technology shocks also contributed to the developments of GDP growth rates during the analysed period. While in the pre-crisis period these shocks had a small but positive impact on GDP growth rates, in periods of the crisis, they contributed importantly to the GDP decline. This result could be considered as associated with the lack of productivity-enhancing and other structural reforms in the run-up to the crisis. On the contrary, transitory (stationary) technology shocks had a stimulating impact, especially from 2013 onwards. This finding may capture the effect of measures adopted to improve production efficiency. The comparison between the two recessions also shows that the role of export mark-up shocks decreased in 2010, from having a significantly negative effect on GDP growth during the period 2008-2009 to making virtually no contribution to the economic downturn between 2012-2013, pointing to a recovery in exports thanks to improving foreign demand, but more importantly, to wage moderation and productivity gains, which translated into considerable competitiveness gains and strong export performance. In addition, consumption preference shocks also importantly contributed to the recovery in GDP growth in the most recent years, which could be interpreted as a consequence of the increased consumer confidence, the resolution of banking system problems and the recovery in the labour market.

The results of historical decompositions have some policy implications. It is important for policy makers to understand what role different shocks play in business cycle in order to assess the potential success of past policy measures adopted. At the same time, the results can also serve as a basis for formulating future economic policy actions. Two results stand out. The first is related with the assessment of past measures adopted regarding the bank resolution. The Slovenian banking system was hit severely by the global economic crisis. Due to the excessive lending and the large drop in economic activity a substantial amount of non-performing loans accumulated on banks' balance sheets. In 2013, several measures to stabilize the banking system were adopted. In 2014, which is a year after bank resolution, the results of historical decomposition of GDP growth show that a major positive effect came from the investment-specific shocks that increased propensity to invest. This was undoubtedly be as a result of the increased confidence in private sector that can be attributed to the resolution of banking system problems. The second important observation is that the negative effects of consumption preference shocks completely disappeared in 2014. This was due to the increased consumer confidence which can also be attributed to bank resolution as this removed the risk of sovereign default and consequently reduced the uncertainty about future incomes. In terms of future policy actions, Slovenia should speed up implementation of structural reforms, which are key to boost economy's competitiveness and growth potential. This policy advice emerges directly from the results of historical decompositions. It can be observed that the permanent (trend) technology shocks which could be considered as associated with structural reforms had mainly negative impact on GDP growth in the recent years, clearly indicating that the pace of structural reforms slowed down. Slovenia is currently facing several challenges, probably the most important being those related to population ageing and shortage of labour force. Therefore, in the near future, the government should undertake labour market reforms, reforms in the education system and adopt appropriate migration policies. Other reforms such as those focused on the overall business environment and taxation would also be much needed and appreciated.

2 EVALUATING FISCAL RULES IN AN ESTIMATED DSGE MODEL

2.1 Introduction

The existence of unsustainable fiscal policies and macroeconomic imbalances across the European Union (EU) member states and the following sovereign debt crisis called for an improvement of the EU fiscal framework, especially for the Euro area, to ensure sound and sustainable public finances as a prerequisite for the stability of the Economic and Monetary Union (EMU) in the short as well as long term (Koester et al., 2013). A prudent fiscal policy, on the one hand, has a positive effect on economic growth and, on the other hand, in the long term, promotes the growth of confidence of the financial markets and contributes to maintaining relatively low interest rates. This translates into higher economic growth and, consequently, contributes to an increase in budget revenues, which in turn results in improving the condition of public finances (European Central Bank, 2004). In recent years, the EU fiscal framework has been strengthened through the adoption of several legislative measures.[33] Fiscal rules, defined as a quantitative restriction on a fiscal indicator, have been one of the most important components of this strengthened fiscal governance framework. In this context, probably one of the most important documents adopted is the Fiscal Compact, signed in 2012, as part of the Treaty on Stability, Coordination and Governance in EMU, that requires ratifying member states to implement budget rule (a so-called debt brake rule) into their national legislations.

While there is a broad literature that has studied the importance of the implementation of fiscal rules (see e.g. IMF, 2009; Kopits & Symansky, 1998; among many others), there is less in the

[33] See Section 2.2 for more details on these measures.

way of the benefits and relative welfare performance of different types of fiscal rules from a general equilibrium stand-point. However, there exists some papers - see e.g. Vogel et al. (2006, 2012), Forni et al. (2009), Mayer & Stähler (2013), Landon & Smith (2017) among others. In this chapter, I want to contribute to the literature by examining the impact on welfare, macroeconomic stabilization as well as on fiscal stability of five different types of fiscal rules using a DSGE model. More specifically, I focus my attention to the optimal simple fiscal rule, the balanced budget rule, the structural balance rule, the basic debt brake (Swiss) rule and the optimal debt brake rule.[34] Some of these rules are more theoretical, such as optimal simple fiscal rule and optimal debt brake rule, while others, such as balanced budget rule, basic debt brake rule and structural balance rule are indeed implemented in practice. As a first rule I consider the optimal simple rule for government consumption with a structure similar to the monetary policy rules that have been extensively studied in the literature, see for e.g. Taylor (1993) and Clarida, Galí, & Gertler (2000) among many others. According to this approach, the government commits itself to a simple fiscal rule for how the government consumption reacts to the consumer inflation, output gap, as well as to the budget deficit and public debt. Rule furthermore allows for instrument smoothing. The government then chooses the feedback coefficients of the rule in such a way that minimizes its loss function, defined as a weighted average of the unconditional variances of consumer inflation and output gap. This is then defined as the optimal simple fiscal rule. The next fiscal rule I consider is the balanced budget rule, which requires that the government expenditure is equal to the projected revenues raised. I also investigate the performance of the structural balance rule, which is designed to produce a structurally balanced budget. Further, I evaluate the debt brake rule, which has been in force in Switzerland since 2003 and has proved very successful in terms of Switzerland's public debt reduction. The key feature of this rule is that it links the maximum level of real expenditure including interest on outstanding debt to the trend revenues. This means that in cyclical downturns spending level is maintained, and during cyclical booms, government saving occurs. Last, I limit the exploration to the optimal debt brake rule, which considers that real government expenditures should be determined according to the observed behaviour in output gap with the feedback coefficient chosen such that the loss function is minimized. Throughout the chapter fiscal policy is carried out in using government consumption as the policy instrument across all considered fiscal policy rules.

The analysis focuses on two main issues. The first is the stabilizing potential of fiscal rules. In particular, I explore the implications of the alternative fiscal rules for macroeconomic volatility by asking the following research questions: what is the volatility of output growth, government consumption growth, budget balance and public debt under different fiscal rules? Which fiscal rule delivers the smallest welfare loss? Second, the analysis makes use of historical counter-factual simulation: it asks how the Slovenian economy (in terms of selected macroeconomic variables) would have performed in the 1995-2014 period if the above mentioned fiscal rules had been in place. But before addressing these two questions, I examine how these different fiscal rules would affect the dynamic properties of the economy. Specifically, I compare fiscal

[34]The specifications of fiscal rules closely follow the paper by Mayer & Stähler (2013). However, this chapter differs from that paper in four aspects. First, I additionally analyse the performance of the optimal simple rule. Second, the coefficient of the optimal debt brake rule is optimized instead of calibrated. Third, contrary to the paper by Mayer & Stähler (2013) in which fiscal rules are analysed by performing impulse response analysis, I perform two additional simulation exercises, namely I (i) determine the extent of volatility of key macroeconomic variables and (ii) run historical counter-factual experiment under various fiscal rules. And last, I use different model which is estimated with Slovenian data.

rules under a negative investment shock to pin down the responses of key variables of interest in terms of their cyclical properties, using impulse response functions. The motivation for considering this exercise is that the estimation results and historical decomposition analysis[35] show that investment shocks accounted for a large share of output growth fluctuations in Slovenian economy during the last recession.

I build the analysis on a small open-economy DSGE model presented in Adolfson et al. (2007) and Masten (2010) and extend the framework by allowing for a richer fiscal policy block (in terms of fiscal rules modelling) with the aim of making the model suitable for the purposes of this chapter. Using quarterly Slovenian macroeconomic data for the period 1995-2014, I estimate the model with Bayesian methods. I then perform two different types of simulation exercises. In the first simulation exercise, I simulate the model based on the structural shocks which are randomly drawn from the normal distribution with a mean of zero and a standard deviations equal to the posterior means. Afterwards, I compute the theoretical standard deviations of key macroeconomic variables around the steady state. In turn, I also compute the associated welfare loss. In the second simulation exercise, I look at how the economy (in terms of selected macroeconomic variables) would have evolved if the above presented fiscal rules would have been applied in the past, where I focus on the period between 1995-2014, with special attention given to the recent recessionary periods. The key idea behind this exercise is to employ the estimated DSGE model that includes various structural shocks as driving forces of business cycle in the economy, use the smoothing algorithm[36] built into the Kalman filter to back out the historical realizations of these shocks, and then perform a simulation experiment to look at how alternative specifications of fiscal policy rules would have performed historically given the sequence of historical estimates of the structural shocks. The main advantage over the structural vector autoregression (SVAR) approach, which is often used to obtain structural shocks, is that I do not need to rely on any outside-the-model identifying assumptions to extract structural shocks. Rather, my approach uses a DSGE model, that is already a structural model, as a framework to recover these shocks. To the best of my knowledge this chapter is the first attempt in a DSGE framework to assess the performance of such set of fiscal rules using the simulation exercises described above.

To preview the results, the optimal simple fiscal rule is found to have the first best performance in terms of welfare loss (measured in output and price variability) amongst all the fiscal rules analysed. The second best performance belongs to the optimal debt brake rule, although I find that this rule can closely approximate the welfare result of the first best performer. The basic debt brake rule and the structural balance rule are ranked third and forth, respectively, while the balanced budget rule exhibits the worst performance. I also find that all the fiscal rules exhibit greater stability of government consumption growth over time as compared to the balanced budget rule case. Regarding the volatility of budget balance and public debt, the analysis reaches the following conclusions. As expected, adopting balanced budget rule and structural balance rule is the best strategy with regard to the budget balance and public debt, but not for the other variables (e.g. output growth), since they exhibit the largest volatility. By contrast, the optimal debt brake rule, which is associated with stronger counter-cyclicality and higher stability of the output growth rate, implies the highest variation in budget balance and public debt. At the same

[35]These results are presented in Chapter 1 of the dissertation.

[36]For more information about the algorithm, see Bauer at al. (2003).

time, the optimal simple fiscal rule and the basic debt brake rule yield lower variability in budget balance and public debt compared to the optimal debt brake rule case. In this respect, I also find that the performance of basic debt brake rule in terms of public debt volatility closely approximates that of the optimal simple fiscal rule. Lastly, the results based on historical counter-factual simulations reveal that with fiscal rule in place, Slovenia's public debt would have been considerably lower compared to the baseline simulation, which replicates the historical data between 1995 and 2014. In practice, low level of public debt would have several positive macroeconomic consequences. It would decrease interest rates, encouraging more investment and capital inflow. It would also have an impact on the formation of optimistic expectations, increase in economic activity and subsequent improvement in public finances.

The analysis in this chapter reveals that fiscal rules all have their advantages and weaknesses. In particular, the simulation results show that different fiscal rules trade off the extent of fiscal stabilization with the degree of countercyclical stabilization. In terms of policy recommendations, the design of fiscal rules should address the need for short-term economic stabilization on the one hand and ensure long term fiscal sustainability on the other hand. This could be achieved by using a combination of different fiscal rules, which is a common practice across the countries implementing rule-based fiscal policy, although using a single rule may offer more simplicity. The success of fiscal rules is also related with other properties such transparency, credibility and implementation, which are frequently discussed in the literature. Regarding the implementation, while some rules are better in delivering best outcomes as per the DSGE results, their implementation may be difficult. For example, based on the results obtained, the optimal fiscal rule is the one that offers the lowest welfare reduction. But this is relatively complicazed – it involves the calculation of output gap and optimized coefficients, which may be difficult to implement in practice as well as to communicate to the public. For this reason, probably better strategy would be to follow the basic debt brake rule, which seems relatively straightforward and easy to understand. In addition, this rule yields a welfare gain and a reduction in volatility similar to that of the more complicated optimal fiscal rule. This is one of the most important findings of the chapter and shows that a good rule need not be complex.

The rest of the chapter is structured as follows. The next section contains a brief overview of the recent reforms of the E(M)U fiscal framework. Section 2.3 provides an overview of the main features of the model and presents its parameterization. In Section 2.4, the most important part of the chapter, I compare the performance of alternative fiscal rules and discuss the results. This section starts by first discussing the characteristics of each fiscal rule in more detail, then I briefly describe the method used to assess the performance of alternative fiscal rules, and in the last part of this section present the results of simulations. Finally, Section 2.5 concludes, draws policy recommendations and proposes some directions for future research.

2.2 A brief overview of the E(M)U fiscal framework

In this section, I briefly review the main changes that have been introduced in the EU fiscal governance framework in recent years. The presentation below mainly follows EC (2015, 2017). Since the creation of the EMU and the single European currency, the EU countries are subject to different common fiscal rules that are placed at the supranational level. The Maastricht Treaty (hereinafter Treaty), signed in 1992, set numerical limits on the government deficit and debt for countries joining the Euro area. According to the provisions of the Treaty, the so-called upper limits are 3 % for the deficit-to-GDP ratio and 60 % for the debt-to-GDP ratio.

In 1997, the EU member states agreed the Stability and Growth Pact (hereinafter the Pact) with the aim of pursuing sound public finances and coordinating their fiscal and economic policies. The Pact consists of two parts, the so-called preventive and corrective arm. The preventive arm is intended to identify the threat of excessive deficit based on stability and convergence programmes and contains measures to prevent its occurrence, while the corrective arm establishes necessary steps intended to correct the excessive deficit including sanctions for violating countries. The Pact has also defined the medium-term budgetary objective in terms of a close to balance or in surplus budget position. The main purpose of the Pact was to ensure fiscal discipline which is essential for price and macroeconomic stability in the monetary union.

In 2005, the Pact has been reformed. In particular, this revision brings a new definition of the medium-term budgetary objective, now defined in terms of a structural balance with a lower limit of -1 % of GDP for the Euro area countries. The exact value of the medium-term objective is set for each country individually, based upon their current debt-to-GDP ratio and long-term potential for growth. The structural balance thus became the central fiscal rule at the EU level, and later also at the national level. The structural balance is defined as a budget balance corrected for the impact of the economic cycle as well as temporary and one-off measures. In order to calculate it, the cyclically adjusted budget balance (CAB) needs to be estimated, which can be, based on the European Commission methodology, estimated according to the following formula (Mourre et al., 2013):

$$CAB = \frac{B}{Y} - \varepsilon \times OG \tag{48}$$

where $B = R - G$ denotes the general government balance in nominal terms calculated as a difference between the government revenue R and expenditure G, Y is GDP, and the cyclical component is the product of the output gap OG and the semi-elasticity ε of the balance-to-GDP ratio with respect to the output gap. The semi-elasticity ε corresponds to the cyclical adjustment parameter and is assumed to be constant. It could be expressed as follows (Mourre et al., 2013):

$$\varepsilon = (\eta_R - 1)\frac{R}{Y} - (\eta_G - 1)\frac{G}{Y}, \tag{49}$$

where η_R and η_G denote the elasticity of revenues and expenditures with respect to GDP, while R/Y and G/Y denote fixed revenue-to-GDP and expenditure-to-GDP ratio, respectively. The methodology for calculating CABs further distinguishes between elasticity of five categories of income (personal taxes, corporate income taxes, indirect taxes, social security contributions, non-tax revenue) and the elasticity of one category of expenditure (unemployment benefits). They correspond to the percentage change in a particular type of category associated with a percentage change in output. Thus, the overall budgetary semi-elasticity ε can be further rewritten as follows (Mourre et al., 2013):

$$\varepsilon = \left(\sum_{i=1}^{5} \eta_{R_i}\frac{R_i}{R} - 1\right)\frac{R}{Y} - \left(\eta_{G_u}\frac{G_u}{G} - 1\right)\frac{G}{Y}, \tag{50}$$

where η_{R_i} and η_{G_u} denote the individual elasticities of five revenue categories and of unemployment expenditure with respect to the output gap, respectively. Further, R_i/R are the weights of the individual revenue categories in total revenue and G_u/G represents the weight of the unemployment related expenditure to total expenditure. The individual elasticities are based on OECD estimates.

Although the structural balance is, at least from a theoretical point of view, a more suitable indicator of the underlying fiscal position than the actual balance, it also has its drawbacks. The main drawback is usually pointed out as the fact that its calculation is based on the unobservable output gap (difference between actual and potential output), which is, due to various methodologies[37] for estimating potential output, subject to considerable variations. Besides the calculation methodology, the variations in output gap estimates and thus structural balance are also affected by the revisions of economic growth and changes in forecasts. Further, the estimates of the structural balance are also affected by the revisions of actual balance and the definition of one-off measures.[38]

The latest recession has revealed a need to increase fiscal discipline of the EU member countries. In recent years EU fiscal governance has been reformed by three sets of legislative measures, specifically, the Six-Pack in 2011, the Treaty on Stability, Coordination and Governance (TSCG) in 2012 and the Two-Pack in 2013. In 2011, the Pact has been amended with six measures, known as the Six-Pack. The most important new features are: an introduction of the European semester, improvement of country surveillance through examining countries with excessive deficit, as well as countries with sound public finances, the possibility of introduction of a procedure related to excessive deficit for countries whose annual deficit is under 3 %, if their debt exceeds 60 % of GDP and is not reduced by 1/20 per year on a three year average, the establishment of a macroeconomic imbalance procedure designed for early detection, prevention and correction of macroeconomic imbalances at member state level and the introduction of expenditure rule in the preventive arm of the Pact, which limits the growth of expenditures to the growth of the potential GDP.

In 2012, the EU member states signed the TSCG aimed at providing a more effective framework

[37]There are two commonly used methods for calculating potential output: the method of Hodrick-Prescott (HP) filter and the method of production function. Based on the HP filter, the potential GDP (trend GDP growth) is calculated by minimizing an objective function that depends on the weighted average of the squared sum of the difference between actual and trend output and the squared sum of the growth of the trend component weighted by a parameter (usually denoted by λ). The production function approach (for a description see D'Auria et al., 2010), which is also the official method of the European Commission and used at the EU level since 2002, computes the potential GDP based on a Cobb-Douglas production function by eliminating cyclical components at individual production factors. Both methods have their shortcomings. Two problems associated with the HP filter are worth mentioning. The first is that the method suffers from an end-point problem, in which the calculation gives more weight to the current data. The second problem arises when the economy is hit by a temporary shock, which can result in a permanent shift in the pattern of potential output, although the shock is only temporary. Thus, corrections at the end of a time series are usually needed. One the other hand, a key limitation of the production function approach is, besides the well-known problem of endogeneity, the difficulty in quantifying/measuring some input data (in particular, labour and capital).

[38]Due to these shortcomings, several authors do not advise the use of the concept of output gap when forming recommendations for economic policy. Marcellino & Musso (2011) analysed long time series of estimates of output gap for OECD countries, made by different institutions. They found that these estimates are very unstable and change significantly over time.

for monitoring implementation of fiscal policies at the EU level. The fiscal part of the TSCG referred to as the Fiscal Compact entails obligation for ratifying member states to introduce into their national legislations the budget rule which requires that, under normal circumstances, the general government budget must be balanced or in surplus. The fiscal rule is considered to be respected if the annual structural balance meets the country-specific medium-term objective and does not exceed a deficit (in structural terms) of either 0.5 % or 1 % of GDP, depending on a country's debt-to-GDP ratio. Besides the mandatory introduction of the budget rule into the national legislation, the Fiscal Compact requires signatory countries to have independent fiscal institution (e.g. fiscal council) in place, which should be in charge of monitoring implementation of national fiscal rules and ensuring their compliance with EU law. The Fiscal Compact also envisages an automatically triggered correction mechanism at the national level in case the structural deficit limit is exceeded and requires member states to include in national legislation information as to when and how they plan to make adjustments for future budgets.

A step further towards increasing fiscal discipline was made in 2013, when other two regulations referred to as the Two-Pack, aimed at providing a greater coordination of national budgetary process in the Euro area, came into force. The first regulation brings a common provisions for monitoring and assessing draft budgetary proposals for the Euro area member states, especially those subject to an excessive deficit procedure. Specifically, by October 15, the member states must submit their draft budget proposals for the following year to the European Commission. If the proposed budget is not acceptable in relation to the EU rules, the European Commission can demand that the national budget proposal be amended. The second regulation is intended to strengthen the economic and budgetary surveillance of member states facing or threatened with serious difficulties with respect to their financial stability in the Euro area. Besides the rules, defined at a supranational level, the EU member states (as well as numerous other countries around the world) have different types of national fiscal rules in place, that can be grouped into four main categories based on the type of budgetary aggregate they seek to constrain: debt rules, balanced budget rules, expenditure rules and revenue rules (Schaechter, Kinda, Budina & Weber, 2012). In the EU, the balanced budget rules are the most frequently used fiscal rules, followed by the rules regarding the amount of public debt, while revenue and expenditure rules are slightly less numerous.

2.3 Model and parameters

2.3.1 Model overview

The DSGE model that I use in this paper closely follows the structure of the model presented in Adolfson et al. (2007) and Masten (2010), which is an extended version of basic closed-economy new-Keynesian models, including the benchmark models of Christiano et al. (2005), Altig et al. (2011), and Smets & Wouters (2003, 2007). Masten (2010) added some additional features to the model of Adolfson et al. (2007). First, in contrast with the paper of Adolfson et al. (2007), which assumes no public debt and budget deficit, he relaxed this assumption by augmenting the fiscal block of the model with equation that describes the debt dynamics. Second, in order to account for the role of automatic stabilizers, he included transfers to households in the model. Last, he adapted the model to the small open economy case within the Euro area. Thus, as a result of the common currency and monetary policy his model disregard nominal exchange rate and assume that the prevailing nominal interest rate in domestic economy is given by the money market interest rate of the Euro area, which in turn is exogenously determined by a vector autoregressive model (VAR), plus a risk premium on foreign bond holdings which depends on net foreign asset position of the domestic economy as well as on exogenous risk premium shocks. For the purposes of this chapter, I further extended the models of Adolfson et al. (2007) and Masten (2010) to include spending rule incorporating the optimal simple fiscal rule, the balanced budget rule, the structural balance rule, the basic debt brake rule or the optimal debt brake rule.

In what follows, I give a general overview of the model structure. The economy consists of households, four types of firms (that is, domestic goods producing firms, importing consumption and importing investment firms and exporting firms), a government which conducts fiscal policy, and an exogenous foreign economy. Households attain utility from consumption and labour supply. The consumption basket consists of domestically produced and imported products, which are supplied by domestic firms and importing firms, respectively. The households can save both in domestic and foreign bonds. Domestic bonds are bought by the government and yield the nominal interest rate, whereas the foreign bonds are bought from the foreign economy and pays the foreign nominal interest rate adjusted by a risk-premium which depends on the aggregate net foreign asset position of the domestic households (Beningo & Beningo, 2003). Further, the households invest in a basket of domestic and imported investment goods to form the physical capital stock, and decide how much capital services to rent to the domestic firms, given certain capital adjustment costs. These are costs to adjusting the investment rate as well as costs of varying the utilization rate of the physical capital stock. Further, along the lines of Erceg et al. (2000), each household is a monopoly supplier of a differentiated labour service which implies that they can set their own wage. This gives rise to a wage equation with Calvo (1983) stickiness. The domestic firms determine the capital services and labour inputs used in their production which is exposed to unit root technology growth as in Altig et al. (2003). The firms (domestic, importing and exporting) all produce differentiated goods and set prices according to a partial indexation variant of the Calvo model. Fiscal policy is modelled as follows: On the expenditure side government makes purchases of domestic goods, provides transfers to households and pays interest on past public debt, while on the revenue side collects taxes from consumption, labour income and capital income. In the baseline specification, the fiscal block of the model is closed by a simple rule, where the government consumption follows the AR(1) process. This seems to be a reasonable assumption given the fact that Slovenia had no specific fiscal rule in place during the sample period used in the estimation of the model. The foreign economy is taken to be exogenous to the domestic small open economy. In particular, I adopt the assumption that the foreign prices, output and interest rate are given by an identified VAR(2) model. Finally, the economic fluctuations in the economy are driven by 16 structural shocks.

2.3.2 Parametrization

To analyse the performance of fiscal rules, I first transform the model into stationary representation by dividing the relevant real variables by the unit-root technology level (denoted by z_t). Next, I log-linearize the model's equations around the non-stochastic steady-state[39]. The solution of the model is then computed in Dynare[40], which uses the method of Klein (2000) and Sims (2002). The model's parameters are either calibrated or estimated. Values for the parameters that are calibrated (and thus kept fixed throughout the estimation) are chosen following standard practice in the literature calibrating small open-economy models. Their values are summarized in Table (1), while the steady state ratios are reported in Table (2). All remaining parameters are estimated with Bayesian estimation method on Slovenian macroeconomic variables during the period 1995Q1-2014Q4. The prior distributions I used in the estimation and the obtained posterior results are available in Table (3) and (4). After the estimation, I performed several checks on the quality of estimation results and the empirical performance of the estimated model. I found that the estimated model is relatively well identified, has good data fit and reasonably estimated parameters.[41] Therefore, it provides a useful framework for conducting the simulations.

2.4 Evaluating fiscal policy rules

This section uses the model described above to evaluate the performance of fiscal rules. First, I analyse the optimal simple fiscal rule for government consumption. According to this rule the government sets its policy instrument (i.e. government consumption) as a linear function of consumer inflation, output gap, budget deficit and public debt in such a way that minimizes its loss function. Second, I study an extreme case of a sustainable fiscal rule, namely the balanced budget rule in which the government is not allowed to spend more than the projected revenues raised. Third, I simulate the model under the structural balance rule. Next, I examine the basic debt brake (Swiss) rule according to which the government ties its expenditures to the trend revenues. Lastly, I focus my attention on optimal debt brake rule which has the same features as the basic debt brake rule, with the only exception being that it is augmented by projected countercyclical component $\mathbb{E}_{t-1}\left\{\left(\bar{Y}_t/Y_t\right)^{\sigma_G}\right\}$, i.e. the output gap, which contains an optimal feedback coefficient σ_G derived by minimizing the government loss function. I start this section by describing each fiscal rule in more detail and proceed to investigate the stabilization and welfare properties of the above mentioned fiscal rules. In this context, I first compare how the proposed fiscal rules affect the economy's response to a negative investment shock which has been found to be the leading source of GDP growth fluctuations observed in the Slovenian economy in the recent recession. Second, I investigate how the standard deviations of output growth, government consumption growth, budget balance and public debt vary in response to shifts in the fiscal policy regime. Third, using historical counter-factual simulations, I simulate how the Slovenian economy would have performed in the 1995-2014 period, if the above proposed fiscal

[39]The steady-state is computed as in Adolfson et al. (2007).

[40]For more information regarding Dynare refer to the official Dynare web page `http://www.dynare.org` or see user and reference manuals: Adjemin, Bastani, Juillard, Mihoubi, Perendia, Ratto & Villemot (2011) and Mancini Griffoli (2011).

[41]Results are available from the author upon request.

rules had been in place.

2.4.1 Specification of fiscal rules

2.4.1.1 The optimal simple fiscal rule

Let me now proceed to the description of fiscal rules. As a first approach to modelling fiscal policy I assume that the government follows an optimal simple fiscal rule. According to this approach the government optimally chooses the feedback coefficients of some pre-specified policy rule to minimize its loss function. This approach has several advantages when compared to fully optimal policy (Jakab et al. 2010):[42] First, the optimal simple rule is simple in the sense that it involves only a limited set of (observed) variables and it is therefore easily explainable to the public. One the other hand, the fully optimal policy is a function of a wide range of observed and unobserved variables and is, therefore, hardly implementable from a government perspective. Second, another argument in favour of the simple fiscal rule is that it is more directly comparable to the estimated (empirical) rule. Third, from a modelling perspective, the optimal simple rule approach is easily implemented with the log-linear model while using a log-linear model with a quadratic loss function to compute fully optimal policy only works for efficient steady states (Benigno & Woodford, 2003). In the subsequent analysis I consider simple fiscal rule for government consumption as a policy instrument in analogy to the Taylor rule for interest rate setting first proposed by Taylor (1993). In particular, I assume that the government sets its policy instrument according to the following rule (in log-linear form):[43]

$$\hat{g}_t = \rho_g \hat{g}_{t-1} - \phi_\pi \hat{\pi}^c_{t-1} - \phi_y \hat{y}_{t-1} - \phi_d \widetilde{def}_{t-1} - \phi_b \hat{b}_{t-1} + \varepsilon_{g,t}, \tag{51}$$

where ϕ_π, ϕ_y, ϕ_d and ϕ_b are the government's reaction coefficients towards inflation, output gap, budget deficit and public debt deviations, respectively. ρ_g is the degree of instrument persistence, and $\varepsilon_{g,t}$ denotes a government spending shock that represents discretionary fiscal policy changes. Equation (51) demonstrates that the evolution of government consumption ($\hat{g}_t$) is determined by fluctuations of the lagged consumer inflation ($\hat{\pi}^c_{t-1}$), output gap ($\hat{y}_{t-1}$), budget deficit ($\widetilde{def}_{t-1}$) and public debt ($\hat{b}_{t-1}$).[44] In particular, when the economy is doing well (i.e. there is a positive output gap) then the government consumption will respond negatively. Similarly, the simple fiscal rule prescribes that the government should react negatively in response to growing inflation. The reason why I include inflation in the rule is that in the New-Keynesian models the stabilization of inflation is necessary to stabilize the output gap (Galí, 2008). Further, an increase in budget deficit and public debt will result in a decline of government consumption with the aim of improving public finances.

[42]More specifically, this type of policy consists in finding the policy function that yield the minimum expected value of a discounted loss function subject to all the non-policy model equations.

[43]My specification for the fiscal rule is similar to those used by Erceg & Lindé (2013), with the only exception that they do not include the inflation rate. Rule of the same specification as mine was also used by Masten & Grdović Gnip (2016).

[44]The imposition of lagged variables in the rule reflects the fact that in practice fiscal policy is limited by political economy constraints and implementation lags.

Regarding the loss function I assume that the government has preferences over output stability, with some concern for inflation stabilization. Although some of the literature attempts to derive a household's welfare based approximation to the loss function consistent with the microfoundations of the model (see for e.g. Galí, 2008; Masten, 2008; Mayer & Stähler, 2013 among others), I restrict my attention, following Adolfson et al. (2014), to an ad hoc loss function. In particular, I formalize preferences of the government with the following period loss function:

$$\mathbb{L}_t = \lambda_\pi \left[p_t^c - p_{t-1}^c - \bar{\pi}^c\right]^2 + \lambda_y \left[y_t - \bar{y}_t\right]^2, \tag{52}$$

where the government's target variables are: the model-consistent quarter-over-quarter CPI inflation rate $p_t^c - p_{t-1}^c$, where p_t^c denotes the log of the CPI; and a measure of output gap $y_t - \bar{y}_t$ (defined as a difference between actual y_t and potential output $\bar{y}_t$). As a measure of output gap I use the trend output gap, which uses the trend output level as a potential output (i.e. $\bar{y}_t = z_t$), which is growing stochastically due to the unit-root stochastic technology shock in the model (Adolfson et al. (2007); Ehrmann, & Smets (2001); Adolfson et al. (2014); Christoffel et al. (2008); Vetlov et al. (2011)). λ_l for $l = \{y, \pi\}$ denotes the relative weight government puts on output gap and inflation stabilization. I assume that contrary to what the central bank does, the government puts more weight on output gap than inflation stabilization. Thus, in the subsequent analysis I use the output-dominated loss function with weights assigned to the output gap and inflation to be $\lambda_y = 1$ and $\lambda_\pi = 0.2$, respectively. Further, it can be shown that for the discount factor δ converging to one the loss function approximately amounts to (Rudebusch & Svensson, 1999):[45]

$$\begin{aligned} \mathbb{E}_t\left[\mathbb{L}_t\right] &= \lim_{\delta \to 1} \mathbb{E}_t \sum_{s=0}^{\infty} (1-\delta)\, \delta^s \mathbb{L}_{t+s} \\ &= \lambda_\pi \mathrm{var}\left[p_t^c - p_{t-1}^c\right] + \lambda_y \mathrm{var}\left[y_t - \bar{y}_t\right], \end{aligned} \tag{53}$$

which is the weighted sum of the variances of the CPI inflation and output gap under the assumption that the unconditional mean of CPI inflation equals inflation target ($\mathbb{E}_t\left[p_t^c - p_{t-1}^c\right] = \bar{\pi}^c$) and the unconditional mean of the output gap equals zero ($\mathbb{E}_t\left[y_t - \bar{y}_t\right] = 0$).

After having specified the simple fiscal rule and described the government's preferences, I search for optimized feedback coefficients such that:[46]

$$\tilde{\varsigma} = \arg\min_{\varsigma} \mathbb{E}_t\left[\mathbb{L}_t\right], \tag{54}$$

where $\varsigma = [\rho_g, \phi_\pi, \phi_y, \phi_d, \phi_b]$ represents the vector of feedback coefficients in (51). This is then defined as the optimal simple fiscal rule. All these computations were done using the optimal simple rule (OSR) routine[47] in Dynare. In general this procedure works as follows (Dennis, 2004): first, the model is augmented with policy rule which can be solved using the standard rational expectations solution methods for given initial values of the feedback coefficients in the policy rule that are optimized later on under the requirement that these initial values yield a determinate rational expectations solution. In the final step the solution of the model is used

[45] This loss function is also used to evaluate alternative fiscal rules in Subsection 2.4.2.

[46] Sine I am studying optimized rule, I set the standard error of the government spending shock to zero.

[47] I used a fmincon optimization algorithm.

in the unconditional loss function that is minimized with respect to the feedback coefficients in order to obtain the optimal simple rule. The resulting optimal simple fiscal rule, therefore, meets the following three conditions: (i) it is simple since it involves only observable variables, (ii) it guarantees uniqueness of the rational expectation equilibrium, (iii) it minimizes the government's loss function.

The obtained optimized feedback coefficients[48] are presented in Table (7). This table also reports the Bayesian posterior mean estimate of the smoothing parameter in the empirical rule and the feedback coefficient on public debt which has been set to the minimum value needed for determinacy of the equilibrium in the model (that is 0.05).[49] From the table, one can see that the optimal simple fiscal rule features a somewhat higher degree of smoothing compared to the estimated rule. It can also be observed that in order to achieve macroeconomic stabilization the optimal simple fiscal rule prescribes strong reactions to output gap and public debt. It means that in response to a decrease in output gap the government needs to raise its consumption, but also aggressively reverts its consumption in response to higher public debt produced by the effort to stabilize output gap and by the budget deficit, which arises from cyclical changes in the economy. On the other hand, the optimal feedback coefficients on inflation and budget deficit are smaller compared to those on output gap and public debt.

Table 7: *Optimized feedback coefficients in the simple fiscal rule*

	ρ_g	ϕ_π	ϕ_y	ϕ_d	ϕ_b
Empirical	0.55	/	/	/	0.05
Optimized	0.58	0.22	0.46	0.21	0.51

Source: Own work.

2.4.1.2 The balanced budget rule

I next assume that the government follows the balanced budget rule requiring that the government expenditure (excluding transfers to households) equals to the projected revenues raised. Furthermore, I assume that any expectation errors, i.e. differences between projected and actual revenues raised are booked on the adjustment account. Total allowable expenditure is then calculated as projected revenues minus previous balances booked on the adjustment account, i.e. $\mathbb{E}_{t-1}\{T_t\} - \rho_{ac}AC_{t-1}$, where $\rho_{ac} \in [0,1]$ is a partial adjustment parameter reflecting an effect earlier expectation errors have on current spending. I set its value equal to 0.05 which is also the choice of Mayer & Stähler (2013). Thus, the actual government expenditure is determined by the following rule:

$$(R_{t-1}-1)B_t + P_t^d G_t = \mathbb{E}_{t-1}\{T_t\} - \rho_{ac}AC_{t-1}, \tag{55}$$

[48]It is important to notice that the feedback coefficients in the optimized simple fiscal rule are optimized on the full set of shocks, not on each shock separately. The same was done by Adolfson et al. (2014).

[49]The coefficient of the public debt must be non-zero, which is needed to ensure the stationarity of public debt.

where the adjustment account is defined as follows:

$$AC_t = (1 - \rho_{ac})\, AC_{t-1} + \mathbb{E}_{t-1}\{T_t\} - T_t. \tag{56}$$

In the above expressions, $(R_{t-1} - 1)\, B_t$ denotes the interest payment on outstanding debt, $P_t^d G_t$ is nominal government consumption of domestic goods, and T_t is total tax revenue. If I express equations (55) and (56) in real normalized terms, that is, by dividing each nominal variable by the aggregate price index of domestic goods, P_t^d, and by stationarizing with the unit-root technology level, z_t, I obtain:

$$(R_{t-1} - 1)\, \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} b_{t-1} + g_t = \mathbb{E}_{t-1}\{t_t\} - \rho_{ac} \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} ac_{t-1} \tag{57}$$

and

$$ac_t = (1 - \rho_{ac})\, \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} ac_{t-1} + \mathbb{E}_{t-1}\{t_t\} - t_t, \tag{58}$$

where lower case letters denote stationarized variables. Log-linearizing this, gives:

$$\begin{aligned} \frac{Rb}{\pi^d \mu_z} \left(\hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t} \right) - \frac{b}{\pi^d \mu_z} \left(\hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t} \right) + g\hat{g}_t \\ = t\mathbb{E}_{t-1}\left\{\hat{t}_t\right\} - \rho_{ac} \frac{1}{\pi^d \mu_z} \widetilde{ac}_{t-1} \end{aligned} \tag{59}$$

and

$$\widetilde{ac}_t = (1 - \rho_{ac})\, \frac{1}{\pi^d \mu_z} \widetilde{ac}_{t-1} + t\mathbb{E}_{t-1}\left\{\hat{t}_t\right\} - t\hat{t}_t, \tag{60}$$

where $\widetilde{ac}_t = ac_t - ac$. A hat above a variable denotes percentage deviation of that variable from its deterministic steady state level, while the variables without time subscripts denote their steady state values.

2.4.1.3 *The structural balance rule*

In this section, I assume that the government commits itself to follow the structural balance rule. Before writing the expression for the structural budget balance, I define the government's actual fiscal position as follows:

$$D_{t+1} \equiv B_{t+1} - B_t = P_t^d G_t + TR_t + (R_{t-1} - 1)\, B_t - \mathbb{E}_{t-1}\{T_t\}. \tag{61}$$

Expressing equation (61) in real terms and stationarizing, I get:

$$\frac{D_{t+1}}{P_t^d z_t} = \frac{G_t}{z_t} + \frac{TR_t}{P_t^d z_t} + (R_{t-1} - 1)\, \frac{B_t P_{t-1}^d z_{t-1}}{P_{t-1}^d z_{t-1} P_t^d z_t} - \mathbb{E}_{t-1}\left\{\frac{T_t}{P_t^d z_t}\right\} \tag{62}$$

or:

$$d_t = g_t + tr_t + (R_{t-1} - 1)\, \frac{b_{t-1}}{\pi_t^d \mu_{z,t}} - \mathbb{E}_{t-1}\{t_t\}, \tag{63}$$

where, as usual, lower-case variables denote real stationarized variables. The structural budget balance is then obtained by correcting the actual budget balance for automatic responses of revenues and transfers resulting from deviations of the bases of revenue components and transfers from their trend values, i.e. z_t. Hence, structural budget balance (denoted by d_t^*) evolves according to:

$$\begin{aligned} d_t^* &= d_t + \mathbb{E}_{t-1}\{t_t\} - tr_t \\ &= g_t + (R_{t-1} - 1)\frac{b_{t-1}}{\pi_t^d \mu_{z,t}}. \end{aligned} \tag{64}$$

Dividing the variables with output y_t and log-linearizing, yields the following expression:

$$\begin{aligned} \tilde{d}_{y,t}^* = d_{y,t}^* - d_y^* &= \frac{g}{y}(\hat{g}_t - \hat{y}_t) + \frac{Rb_y}{\pi^d \mu_z}\hat{R}_{t-1} \\ &+ \frac{(R-1)\,b_y}{\pi^d \mu_z}\left(\hat{b}_{y,t-1} + \hat{y}_{t-1} - \hat{y}_t - \hat{\pi}_t^d - \hat{\mu}_{z,t}\right), \end{aligned} \tag{65}$$

where $d_{y,t}^* \equiv \frac{d_t^*}{y_t}$ and $b_{y,t-1} \equiv \frac{b_{t-1}}{y_{t-1}}$. Further, I assume that the structural budget balance is adjusted according to the following log-linear rule (Bilbiie et al., 2008):

$$\tilde{d}_{y,t}^* = \phi_d \tilde{d}_{y,t-1}^* + \phi_b \hat{b}_{y,t-1}, \tag{66}$$

where the parameter ϕ_d captures the possibility that budget decisions are autocorrelated and the parameter ϕ_b governs the response of the deficit to the beginning-of-period ratio of debt to GDP, hence capturing a debt stabilization motive: a negative value of ϕ_b indicates that deficits are adjusted in order to stabilize outstanding debt. For simulation purposes, I set $\phi_d = 0.46$ and $\phi_b = 0.02$.

2.4.1.4 The basic debt brake rule

The next fiscal rule I consider is the debt brake rule adopted by Switzerland and some other countries.[50] At the core of the debt brake rule is an expenditure rule, which can be formalised by the following general formula:[51]

$$GEX_t^* = k_t T_t \quad \text{with} \quad k_t = \frac{\bar{Y}_t}{Y_t}. \tag{67}$$

[50] The Swiss fiscal rule was approved in a referendum by 85 percent of voters. It is anchored in the Swiss constitution and cannot be changed without a popular vote. The rule employed in equation (67) is simplified since Switzerland's rule offers an escape clause for uncontrollable situations. In this case, a record of deviations from the rule is kept in a notional compensation account and deficits in that account must be subsequently eliminated. Variations on the Swiss debt brake rule have also been adopted in Germany (Kastrop et al., 2009) and Austria (Steger, 2010).

[51] The starting point for deriving the formula for the debt brake rule is the structural budget balance (SBB), which is defined as follows:

$$SBB = T\left(\frac{\bar{Y}_t}{Y_t}\right)^{\varepsilon_T} - GEX\left(\frac{\bar{Y}_t}{Y_t}\right)^{\varepsilon_E}.$$

According to this formula, tax revenues (T) and expenditure (GEX) are corrected for the effect that arises as a result of the deviation of real GDP (Y) from its potential level ($\bar{Y}$). The elasticity of tax revenues (ε_T) and expenditure (ε_E) in relation to the output gap ($\frac{\bar{Y}}{Y}$) shows how strongly tax revenues and expenditure react to the economic cycle. The debt brake concept assumes that tax revenues react proportionally to changes in the output gap ($\varepsilon_T = 1$) and that expenditure is not influenced by the economic cycle ($\varepsilon_E = 0$). At the same time, the debt brake demands a structurally balanced fiscal balance ($SBB = 0$). By incorporating this into above equation and undertaking subsequent simplifications, I arrive at the debt brake formula presented in the main text.

This formula states that in any calculation period (t), the maximum allowed level of government expenditures (GEX_t^*) must equal revenues (T_t), after multiplication by the business cycle adjustment factor (k_t). The factor k_t is a ratio between the potential ($\bar{Y}_t$) and actual (Y_t) output (also referred to as output gap). If the factor k is larger than one (when actual output is below potential output, $Y_t < \bar{Y}_t$), a deficit is allowed (cyclical deficit), whereas if the factor k_t is smaller than one (when actual output is greater than potential output, $Y_t > \bar{Y}_t$), a (cyclical) budgetary surplus is required. Put differently, when the economy is weak and economic activity is below potential level (i.e. there is a negative output gap), expenditures are allowed to exceed revenues by a factor by which the potential GDP exceeds predicted GDP. Conversely, when the economy is above potential output (i.e. there is a positive output gap), the debt brake rule prescribes that expenditures should be lower than the predicted revenues, namely by a factor by which the predicted GDP exceeds potential GDP. Contrary to the balanced budget rule, the debt brake rule does not require balanced budget in every period but instead it is counter-cyclical by construction and runs a balanced budget throughout the full business cycle (i.e. the phase of recession and expansion). In times of recession, the government is allowed to run a deficit in order to mitigate the impact of the crisis (e.g. achieved through social transfers increases) and to promote economic growth (e.g. achieved through tax rate reductions and public investment increases) whereas during the expansion phase the government accumulates surpluses which can be used to repay outstanding debt or can be saved for the bad times. Summing up, the debt brake rule therefore addresses two objectives of fiscal policy: ensuring the sustainability of public finances and smoothing business cycle. Let me now proceed to define the debt brake rule taking into account the specific setting of the present model. The debt brake rule, in nominal terms, takes the form:

$$\left(R_{t-1}-1\right)B_t + P_t^d G_t = \mathbb{E}_{t-1}\left\{T_t \frac{\bar{Y}_t}{Y_t}\right\} - \rho_{ac} AC_{t-1}, \tag{68}$$

where the adjustment account reads as:

$$AC_t = \left(1-\rho_{ac}\right) AC_{t-1} + \mathbb{E}_{t-1}\left\{T_t \frac{\bar{Y}_t}{Y_t}\right\} - T_t \frac{\bar{Y}_t}{Y_t}. \tag{69}$$

I define the potential output, $\bar{Y}_t$, as a model-based (stochastic) trend output level, that is $\bar{Y}_t = z_t$. Expressing equations (68) and (69) in real terms (i.e. dividing by P_t^d), normalizing (i.e. dividing by z_t) and using the definition of potential output, I obtain:

$$\left(R_{t-1}-1\right) \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} b_{t-1} + g_t = \mathbb{E}_{t-1}\left\{t_t \frac{z_t}{Y_t}\right\} - \rho_{ac} \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} ac_{t-1} \tag{70}$$

and

$$ac_t = \left(1-\rho_{ac}\right) \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} ac_{t-1} + \mathbb{E}_{t-1}\left\{t_t \frac{z_t}{Y_t}\right\} - t_t \frac{z_t}{Y_t}. \tag{71}$$

Written in deviation from the steady state, the debt brake rule and the adjustment account has the form:

$$\begin{aligned} \frac{Rb}{\pi^d \mu_z}\left(\hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t}\right) - \frac{b}{\pi^d \mu_z}\left(\hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t}\right) + g\hat{g}_t \\ = \frac{t}{y}\mathbb{E}_{t-1}\left\{\hat{t}_t - \hat{y}_t\right\} - \frac{1}{\pi^d \mu_z}\rho_{ac}\widetilde{ac}_{t-1} \end{aligned} \tag{72}$$

and

$$\widetilde{ac}_t = \frac{1}{\pi^d \mu_z} (1-\rho_{ac}) \widetilde{ac}_{t-1} + \frac{t}{y} \mathbb{E}_{t-1} \left\{ \hat{t}_t - \hat{y}_t \right\} - \frac{t}{y} \left(\hat{t}_t - \hat{y}_t \right), \tag{73}$$

respectively. A general problem with this specification is that it may imply a pro-cyclical reaction to exogenous shocks. In other words, what this mean is that, given a positive shock, government real revenues may increase by more than the counter-cyclical component to dampen expenditures, which implies an increase in government expenditures following a positive shock. This is at odds with the basic idea of the debt brake rule, which says that government expenditures should not react. For this reason, I rewrite the formula for the debt brake rule, which is then used in the simulation exercise below, in the following way:

$$(R_{t-1} - 1) B_t + P_t^d G_t = z_t - \rho_{ac} AC_{t-1}, \tag{74}$$

where the adjustment account evolves according to:

$$AC_t = (1-\rho_{ac}) AC_{t-1} + z_t - T_t. \tag{75}$$

According to the above specification, government expenditures, including interest on outstanding debt, are equal to the trend level of technology, i.e. z_t in the model. The rule therefore implicitly allows for a counter-cyclical fiscal policy, because, whenever revenue is above trend level, the government saves, while in times of revenue below trend level, the government debt-finances part of its expenditures. Expressing these equations in real normalized terms, I find:

$$(R_{t-1} - 1) \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} b_{t-1} + g_t = 1 - \rho_{ac} \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} ac_{t-1} \tag{76}$$

and

$$ac_t = (1-\rho_{ac}) \frac{P_{t-1}^d z_{t-1}}{P_t^d z_t} ac_{t-1} + 1 - t_t. \tag{77}$$

Log-linearizing the two preceding expressions, yields:

$$\begin{aligned} \frac{Rb}{\pi^d \mu_z} \left(\hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t} \right) - \frac{b}{\pi^d \mu_z} \left(\hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t} \right) + g \hat{g}_t \\ = -\frac{1}{\pi^d \mu_z} \rho_{ac} \widetilde{ac}_{t-1} \end{aligned} \tag{78}$$

and

$$\widetilde{ac}_t = \frac{1}{\pi^d \mu_z} (1-\rho_{ac}) \widetilde{ac}_{t-1} - t \hat{t}_t. \tag{79}$$

2.4.1.5 The optimal debt brake rule

To allow for a more highly counter-cyclical debt brake rule, I add to the basic debt brake rule an additional output gap term, i.e. $\mathbb{E}_{t-1} \left\{ \left(\bar{Y}_t / Y_t \right)^{\sigma_G} \right\}$, where the coefficient σ_G determines the magnitude of the counter-cyclical stance taken by the rule. The rule (74) then becomes:

$$(R_{t-1} - 1) B_t + P_t^d G_t = z_t \mathbb{E}_{t-1} \left\{ \left(\frac{\bar{Y}_t}{Y_t} \right)^{\sigma_G} \right\} - \rho_{ac} AC_{t-1} \tag{80}$$

and the adjustment account is now defined as follows:

$$AC_t = (1 - \rho_{ac})\, AC_{t-1} + z_t \mathbb{E}_{t-1} \left\{ \left(\frac{\bar{Y}_t}{Y_t} \right)^{\sigma_G} \right\}. \tag{81}$$

Now, the log-linearized equations can be written as follows:

$$\begin{aligned} \frac{Rb}{\pi^d \mu_z} \left(\hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t} \right) - \frac{b}{\pi^d \mu_z} \left(\hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t} \right) + g\hat{g}_t \\ = -\sigma_G \frac{1}{y^{\sigma_G}} \mathbb{E}_{t-1} \left\{ \hat{y}_t \right\} - \frac{1}{\pi^d \mu_z} \rho_{ac} \widetilde{ac}_{t-1} \end{aligned} \tag{82}$$

and

$$\widetilde{ac}_t = \frac{1}{\pi^d \mu_z} (1 - \rho_{ac})\, \widetilde{ac}_{t-1} - \sigma_G \frac{1}{y^{\sigma_G}} \mathbb{E}_{t-1} \left\{ \hat{y}_t \right\}. \tag{83}$$

I then search for optimized coefficient σ_G which delivers the smallest welfare loss by following exactly the same procedure as described in Subsection 2.4.1.1. I find that the optimal debt brake rule, for the preference parameters in the loss function $\lambda_y = 1$ and $\lambda_\pi = 0.2$ for the output gap and the consumer inflation, respectively, calls for a fiscal policy characterized by value of coefficient on output gap that is below unity ($\sigma_G = 0.39$).

2.4.2 Simulation results and discussion

2.4.2.1 Impulse-response analysis

In this section, I explore the properties of the fiscal rules just described through the impulse response of selected macroeconomic variables to a negative investment shock. Before I turn to deal with the impulse response analysis, let me first give an economic motivation for considering this exercise. The economic developments in Slovenia in recent years have been characterized by a sharp decline in economic growth. Since 2008, Slovenia has experienced a double-dip recession. Based on the historical decomposition of GDP growth I found that the investment shock accounted for a significant portion of drop in output in the recent recession. This can be explained as follows: With the onset of recession, the Slovenian banking system accumulated a large amount of non-performing bad loans resulting in a credit crunch which in turn caused a cutback in corporate investment and impeded economic activity. Given the importance of investment shock in explaining business cycle fluctuations in the Slovenian economy, I explore the fiscal rules' key features through the impulse responses of some key variables to the negative investment shock which in turn is captured through a one-standard deviation decrease of innovation in the initial period.

The results for the simulation with the posterior mean parameters are presented in Figure (2), which portrays the response of output growth, government consumption growth, budget deficit and public debt. In each panel, the black line reflects the dynamic of the macroeconomic variables when the shock hits the economy under BBR, the orange line represents the responses of the economy under SBR, the red line depicts the paths of relevant macroeconomic variables under OSR, the green line represents the impulse response functions under DBR whereas the blue line reflects the model economy under OptDBR. The upper right panel of Figure (2) depicts the response of government consumption growth under the different fiscal rules. One can see that the fiscal policy conducted in accordance with both the OptDBR and OSR calls for increases in government consumption. It is a counter-cyclical action, spending more on the purchase of goods and services to increase overall aggregate demand, when the economy is in recessionary period. As it is clear, the largest increase in government consumption is, after two quarters, achieved under the OptDBR, while under the OSR the government raises its consumption less aggressively. Further, one can observe that with the DBR, government consumption does not react to a negative investment shock which is in line with the basic idea of this rule which states that government consumption should not react. By contrast, the BBR and SBR require government to reduce its consumption, which is a consequence of the fall in tax revenues in the case of the BBR and the higher level of deficits in the case of the SBR. Further, as can be seen from the upper left panel in Figure (2), which plots the impulse response function of output growth for each of the considered fiscal rules, the impact of the negative investment shock on the output growth under both the BBR and the SBR is the most damaging, while the smallest negative effect is observed under the OptDBR. The behaviour of the output growth of the OSR and DBR lies somewhere between. It is also noteworthy that the impulse response of the DBR is very close to that of the OSR. Focusing on the results for the budget balance[52] (depicted in the bottom left panel of Figure (2)), one can see that the OptDBR leads to the highest increase in budget deficit among all five fiscal rules under consideration, while under the remaining fiscal rules the negative investment shock has noticeable smaller effect on the budget deficit. The comparison of the OSR and the DBR indicates that budget deficit dynamics is a little larger for the OSR than for the DBR during the first five years then quickly returns and slightly overshoots the steady state as the shock fades away while the DBR generates more persistent budget deficit effect. Lastly, looking at the impulse responses of public debt (see the bottom right panel of Figure (2)), one can observe that the effects of the negative investment shock on the public debt dynamics are similar to those discussed previously with budget deficit simulation.

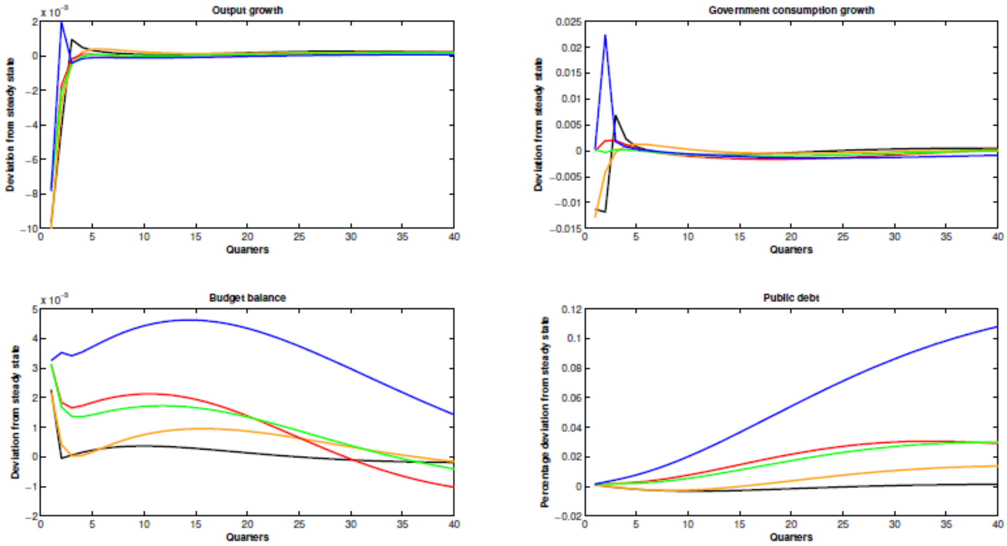
2.4.2.2 Macroeconomic volatility and welfare comparison

After having investigated the economy's response to a negative investment shock, two simulation experiments are performed based on an estimated DSGE model described above. First, I am interested in comparing the macroeconomic volatility of key variables that arises from different assumptions regarding fiscal rules. Second, to shed further light on the implications of the five fiscal rules on the business cycles of a small open economy in the case of Slovenia, I also conduct a counter-factual experiment where I evaluate how these rules would have performed historically in the 1995-2014 period. In discussing the results, I focus the attention on the following variables that are likely to be of main concern for fiscal policy: output growth, government consumption growth, budget balance and public debt.

In this section, I first proceed with the investigation of macroeconomic volatility performance across alternative fiscal rules. On the one hand, I want to explore the performance of proposed fiscal rules in terms of their stabilization properties by measuring the variability of output and

[52] Budget deficit is defined positive.

Figure 2: *Impulse response functions to a negative investment shock under alternative fiscal rules*



Legend: black: BBR, orange: SBR, red: OSR, green: DBR, blue: OptDBR.

Source: Own work.

government consumption growth over the simulation period. On the other hand, I also want to estimate the budgetary impact of fiscal rules. To this end, I carry out a simulation exercise to obtain the standard deviation of the variables of interest under different types of fiscal rules. Specifically, the simulation procedure proceeds as follows. The model has been simulated 10.000 times. In each iteration the data are generated in the following way. The model contains 16 structural shocks. These shocks are then randomly generated under the assumption of normal distribution with corresponding standard deviations set to posterior means. The length of the generated time series is set to 400, of which I take the last 200 observations and compute the averages over the 200 simulations of the standard deviation of each variable of interest. Since Slovenia had no specific fiscal rule in place during the sample period, I do not incorporate any fiscal rule in the baseline model. Rather, when estimating the model, I simply assume that government consumption follows a simple AR(1) process with a shock and is also affected by fluctuations in public debt, which is necessary for stability of the model. In this sense any DSGE model allowing for public debt incorporates some sort of the debt brake. For the purpose of the evaluation of alternative fiscal rules, the AR(1) process for government consumption is either dropped out of the model when solving the model under BBR, SBR, DBR and OptDBR or modified to an OSR. It is also worth noting that when the model is solved under the BBR, SBR, DBR and OptDBR, I do not specify any specific process for government consumption. I simply assume that it adjusts endogenously to ensure that the respective fiscal rule is fulfilled. Table (8) compares the macroeconomic volatility around the steady state (measured as standard deviation) of key variables among five alternative fiscal rules under consideration. The simulation results clearly show that the fiscal policy conducted according to the BBR generates the highest output growth volatility.[53] This reflects the fact that the BBR is pro-cyclical

[53] I have also experimented with a simple fiscal rule that requires current government expenditures to be deter-

by construction, restraining government from pursuing stabilization policy over the business cycle. One can further observe that the volatility of output growth when fiscal policy is conducted according to the OSR and the OptDBR is significantly lower than with the BBR case. This result is based on the fact that, in both cases, fiscal policy explicitly reacts to the output gap in a counter-cyclical manner, forcing government to spend relatively more in bad times and less in good times. The volatility of output growth associated with the DBR is somewhat larger than two preceding rules. The reason for such a result is that the DBR only implicitly accounts for the output-stabilization motive. Next, the results show that all the fiscal rules that I consider exhibit greater stability of government consumption growth over time as compared to the pro-cyclical balanced budget rule. It can be observed that the volatility of government consumption growth path is the least volatile under the OSR, followed by the DBR, the OptDBR and the SBR. Based on the results of budget balance and public debt volatility, the following conclusions can be reached. Comparing the volatility of budget balance under the DBR and the OptDBR indicates that the lower volatility of output growth under the OptDBR comes at the cost of a more volatile budget balance, which is an expected result given that this rule implies a more active fiscal policy. Same observation applies to public debt. Not surprisingly, the volatility of the budget balance and public debt is the lowest under the BBR and SBR. Next, the results indicate that in the case of public debt volatility, the DBR and the OSR yield quite similar results. Further, the results show that although the OSR and OptDBR deliver quite comparable results for the output growth volatility, the former is more successful in reducing the volatility of public debt. The intuition behind this result can be explained by the fact that the OSR allows for a direct policy reaction to the public debt. For example, in times of recession, the rule requires the government to increase its consumption. At the same time, as GDP falls during a recession, tax revenues fall and transfer payments increase, so the budget balance automatically deteriorates. Such a deterioration in public finances requires lower government consumption, which makes public debt less volatile under the OSR. Precisely the opposite process occurs in an expansion. The inclusion of the public debt feedback term in the rule also implies that the government faces a trade-off between the lower (larger) public debt fluctuations and the larger (lower) deviations of output gap from its steady state level. Nevertheless, I argue that the debt correction mechanism, through a policy reaction to public debt, is an important component of the simple fiscal rule equation, since it does not increase volatility of output gap by much and significantly reduces the volatility of the public debt.[54]

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mined by a moving average of past government revenues (i.e. the moving average fiscal rule) (Landon & Smith, 2017):

$$\left(R_{t-1}-1\right)B_t + P_t^d G_t = \frac{1}{n}\sum_{j=1}^{n} T_{t-j}.$$

After log-linearization, the moving average fiscal rule reads as:

$$\begin{aligned}\frac{Rb}{\pi^d \mu_z}\left(\hat{R}_{t-1}+\hat{b}_{t-1}-\hat{\pi}_t^d-\hat{\mu}_{z,t}\right)-\frac{b}{\pi^d \mu_z}\left(\hat{b}_{t-1}-\hat{\pi}_t^d-\hat{\mu}_{z,t}\right)+g\hat{g}_t \\ =\frac{1}{n}\frac{t}{\pi^d \mu_z}\sum_{j=1}^{n}\left(\hat{t}_{t-j}-\hat{\pi}_{t-j}^d-\hat{\mu}_{z,t-j}\right).\end{aligned}$$

In the simulation, I use value for n of 8 (i.e. 2 years). The results show that this rule reduces the variability of output growth by about 50 % relative to the balanced budget rule.

[54]Results are available from the author upon request.

Table 8: *Macroeconomic volatility around the steady state (measured as standard deviation) of some key variables under alternative fiscal rules*

Variables	BBR	OSR	SBR	DBR	OptDBR
Output growth	2.67	1.28	1.95	1.50	1.31
Gov. consumption growth	10.66	2.08	5.38	3.79	4.14
Budget balance	1.01	2.42	1.56	1.95	4.12
Public debt	13.63	26.83	15.49	27.64	158.99

Notes: BBR: Balanced budget rule; OSR: Optimal simple fiscal rule; SBR: Structual balance rule; DBR: Basic debt brake rule; OptDBR: Optimal debt brake rule

Source: Own work.

In order to evaluate the overall performance of fiscal rules considered in this chapter in the sense of which of them delivers the smallest welfare loss, for each of the fiscal rules unconditional variance of the variables that enter the loss function and associated per-period value of the loss function are reported in Table 9. The reported loss function values are expressed relative to the value of the loss function of the baseline, where the baseline is a balanced budget policy. As the baseline involves no stabilization, it is a useful benchmark to compare the performance of the fiscal rules because it generates a level of welfare that any fiscal rule would be expected to meet or exceed. This means that the table below shows me the welfare consequences of following supra-optimal fiscal rules. As can be seen from the table, the OSR has the first best performance within the set I consider. That is, shifting to the OSR from the BBR one creates a welfare gain amounting to 50 %. The second best performance belongs to the OptDBR, although results show that this rule can closely approximate the welfare result of the first best performer. Further, the third best performance occurs when the government follows the DBR. In this case, the welfare loss is 42 % lower of what it would be if government consumption equalled revenue every period. Lastly, the SBR is ranked forth with welfare loss lower by 26 %, relative to a policy of balancing the budget each period.

Table 9: *Unconditional losses under alternative fiscal rules ($\lambda_\pi = 0.2$ and $\lambda_y = 1$)*

Type of fiscal rule	Var (π_t^c)	Var $(y_t - \bar{y}_t)$	$\frac{\mathbb{E}_t[\mathbb{L}_t]^{i \in \{\text{BBR,OSR,SBR,DBR,OptDBR}\}}}{\mathbb{E}_t[\mathbb{L}_t]^{\text{BBR}}}$
BBR	0.52	2.67	1
OSR	0.54	1.28	0.50
SBR	0.52	1.95	0.74
DBR	0.53	1.50	0.58
OptDBR	0.54	1.31	0.51

Notes: BBR: Balanced budget rule; OSR: Optimal simple fiscal rule; SBR: Structual balance rule; DBR: Basic debt brake rule; OptDBR: Optimal debt brake rule

Source: Own work.

2.4.2.3 *Historical counter-factual analysis*

In the previous section, I examined the comparative performance of alternative fiscal rules based on the asymptotic stochastic properties of the model. Now, I explore how the above described fiscal rules would have performed in a particular period of time. In particular, I focus my attention on the Slovenian economy over the sample period 1995-2014, with special emphasis given to the recent recessionary periods. But before proceeding with the results of the simulation, I briefly present the general macroeconomic situation and public finance dynamics in Slovenia throughout this period. The presentation in the following follows Verbič et al. (2016).

In the years prior to the crisis Slovenia was characterized by rapid growth in GDP of around 4 %. Regarding the fiscal situation, over the period 1995-2010 Slovenia has run a deficit every year except 2007 when a smallest surplus was registered (0.1 % of GDP). However, government indebtedness has been relatively low with government debt ratio below 20 % of GDP in 1995, increasing to 38 % of GDP by 2010, still well below the 60 % reference value. Regarding the fiscal policy orientation, Slovenia as well as most Euro area countries applied pro-cyclical and expansionary fiscal policy throughout this period, especially in the years 2005-2008, which resulted in a deterioration of the structural budget balance and the overall fiscal position of the Slovenian economy at the start of the economic and financial crisis (Mencinger & Aristovnik, 2014). When the recession hit the global economy, Slovenia suffered from one of the highest falls in economic activity among the EU member states, as well as one of the largest deterioration in the public finances. In 2009, GDP fell by about 8 % and continued to contract until 2012-2013, when another significant reduction in economic activity took place, with GDP growth of -2.7 % for 2013, as compared to 2012. Turning to the Slovenia's fiscal deficit, it has risen significantly from near zero in 2007-2008 to 15 % of GDP in 2013. Public debt has also been trending upwards increased to 80 % of GDP in the end of 2014 after 22 % in the end of 2007. The main reasons of the deterioration of fiscal position lie in a combination of effects of an automatic deterioration of public finances due to the economic downturn and discretionary measures taken by the government, particularly the capitalization of the banking system, the measures to alleviate the social impacts of the crisis as well as several other measures to boost the economy. During the initial stage of the crisis, the government attempted to counteract the effects of the crisis by raising social transfers and benefits for private companies. This together with a declining revenues led to a strong increase in deficit in 2009, accounting for -5.9 % of GDP. As a consequence of this situation, Slovenia was placed in the Excessive Debt Procedure of the SPG in December 2009. To make public finances in order in the years ahead, several consolidation measures have been taken. They mainly relied on withdrawal of the fiscal stimulus and improvement of the efficiency of the public expenditures. Only in 2012, Slovenia started with a fiscal consolidation and the reduction in almost all categories of total expenditure. The gap between the revenues and expenditures nevertheless closed only slowly due to the significant impact of recapitalization of banks and some state-owned enterprises. In order to stabilize public debt in accordance with the EU regulations contained in the SGP and the Fiscal Compact and to ensure long-term fiscal consolidation, another important step has been taken. On 24th of May 2013, the Slovenian Parliament endorsed the introduction of balanced budget rule into the Constitution, prescribing that all revenues and expenditures of the state shall be balanced without incurring new debt, or revenue must exceed expenditure. The implementation law, which determines more precisely the fiscal rule, was approved by parliamentary parties on 10th of July 2015. After exiting recession in 2013, the Slovenian economy grew by 3.1 % in 2014 as compared to the year 2013. The state of public finances has also started to improve, particularly due to the adopted economic policy measures, the recovery of economic activity and the absence of large one-off negative effects. In 2015 Slovenia reduced its general government deficit to 2.9 % of GDP, the lowest level since the beginning of the crisis. Thereby it corrected the excessive deficit and exited the corrective arm of the SGP in 2016. The growth of public debt has also slowed in 2015.

Having described the Slovenian macroeconomic situation in the past years, I now ask the question how the selected macroeconomic variables in Slovenia would have evolved if the government had been following different types of fiscal rules considered in this chapter. In particular, I simulate the counter-factual dynamics of the selected macroeconomic variables under the alternative fiscal rules and compare it with the historical (smoothed) data in order to explore the changes to the fiscal policy regime. Consistently with the previous analysis, I focus my attention on four key variables: output growth, government consumption growth, budget balance and public debt. The essential concept in this respect are the historical estimates of structural shocks that affected the Slovenian economy in that period. I retrieve these shocks directly from an estimated DSGE model (that is the model which assumes the AR(1) process for government consumption, i.e. the case without any fiscal rule) using the Kalman smoothing algorithm from the state space representation of the estimated model.[55] The resulting estimates of structural shocks, once fed into the state space representation of the model, generate time series for all the model's variables. I then replace the exogenous AR(1) process for government consumption with the above suggested fiscal rules, assuming that all the parameters and structural shocks remained unchanged, to generate time series for the alternative fiscal rules.[56] In what follows, I present and discuss the results obtained from simulation runs. The simulation results are depicted in Figure (3), which compares the historical (smoothed) series (black line) for the four variables of interest against the simulated series that would have been generated under alternative fiscal rules, where the orange line represents the case for balanced budget rule, the grey line depicts the case for structural budget rule, the red line shows the case for optimal simple fiscal rule, the green line depicts the case for basic debt brake rule and the blue line represents the case for optimal debt brake rule.

In the upper left panel, I first show the counter-factual pattern for the output growth rate. As can be seen, the OSR and the OptDBR both would have implied a smaller contraction of output growth rate in the 2008-2009 recession, while the results concerning the 2012-2013 recession are less clear since the actual outcome for output growth is much closer in line with these two rules when compared with the first recession. Limiting attention to the first recession only, one

[55] The most common approach in the literature to obtain structural shocks utilizes a structural vector autoregressive model (SVAR). Although attractive in theory, this approach suffers from an identification problem as the parameters of the SVAR model are not directly estimable. To overcome this limitation one needs to rely on a reduced-form VAR model and make assumptions to recover the mapping between structural shocks and reduced-form VAR residuals. To this end several identification schemes have been proposed in the literature (see e.g. Blanchard & Quah, 1989; Del Negro & Schorfheide, 2004 among others). Despite its efficiency in handling the identification problem, the effectiveness of this approach is limited because it is based on model identification assumptions outside the model to estimate any structural shocks. Additionally, different identification schemes may generate notably different structural shocks estimates. For these reasons, I use the estimated DSGE model which has the structural shocks built in and thus it is already a structural model. For a discussion, see Bauer et al. (2005).

[56] For a more detailed description of the simulation procedure, see Appendix M.

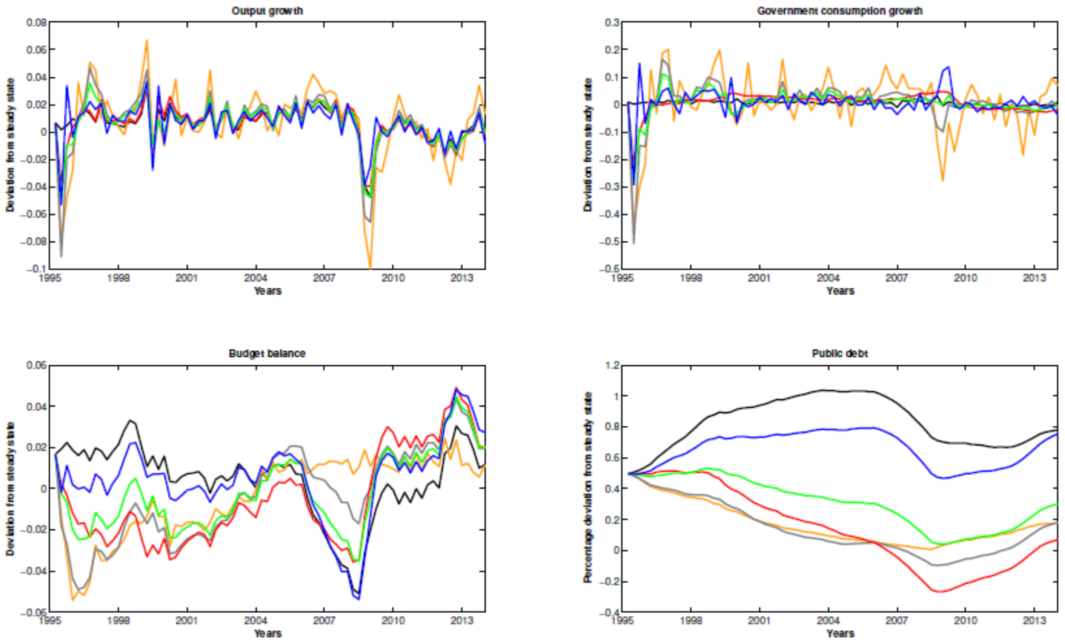
can see that the OptDBR would have done slightly better than the OSR. On the contrary, it can be observed that the two recessions in Slovenia would have been even more severe than those actually observed, if the government had been following either the BBR or the SBR, while the path of output growth would have not differed considerably between the counter-factual DBR and actual series. Comparing the performance of fiscal rules for the entire 1995-2014 period, the best rule in terms of minimizing macroeconomic volatility around the steady state would have been the OSR. The second best performing rule would have occurred under the OptDBR, followed by the DBR and the SBR. The BBR would have given the worst performance within the class considered here. These results are in line with those found in Subsection 2.4.2.2.

Next, the upper right panel of Figure (3), which depicts the evolution of government consumption growth, shows that with all fiscal rules considered, it would be possible to increase government consumption growth stability, compared to the BBR case. The greatest stabilization, as indicated by the smallest standard deviation around the steady state, results with the OSR, which is not much lower than the standard deviation implied by the DBR which exhibits the second best performance. Taking a closer look at the effects of fiscal rules during the recession, one can observe that under both the OSR and OptDBR the economy would have experienced positive growth rates of government consumption in both recessionary periods, especially in the first recession. By contrast, with the BBR and SBR, government consumption growth would have been negative, while with the DBR it would have remained relatively stable.

Turning attention now to the evolution of budget balance (see left panel of Figure (3)), the results are the following. In the pre-crisis period, the simulation results suggest that the government would have been forced into creating smaller deficits (or even surpluses) under examined fiscal rules compared to the case that corresponds to the policy without fiscal rule. On the other hand, looking at the periods of recession, the results show that the government would have been allowed to run looser fiscal policy. In this respect, it can be seen that of all the fiscal rules considered, the OSR would have permitted government to run the largest deficit, while the remaining rules would have implied less expansionary budget and somewhat tighter expenditures control, but with budget balance level still above that of realised under the no fiscal rule scenario.

Perhaps the most interesting message coming out of this counter-factual analysis is the comparison of the simulation results for public debt, depicted in the lower right panel of Figure (3). One can see that the path of public debt would have been well below the path consistent with the no fiscal rule scenario, if the economy had adopted fiscal rule. This suggests that the adoption of fiscal rule would have contributed significantly to stabilize debt dynamics. This finding is generally consistent with that of previous studies (see, for example, Andrle et al., 2015). In that regard, the best-performing rule would have been the BBR, with SBR ranking second, OSR third, DBR forth and OptDBR fifth. Regarding public debt simulations, it also needs to be emphasised that the simulations performed abstract from the fact that because of a lower public debt investors would have become less concerned about the sustainability of the public finances which in turn would have reduced sovereign default risk, thus lowering the risk premium demanded by the investors and making public debt less expensive. This implies that the level of public debt would have been even lower than simulated here.

Figure 3: *Historical (smoothed) and simulated time series of some key variables under alternative fiscal rules*



Legend: black: smoothed, orange: BBR, gray: SBR, red: OSR, green: DBR, blue: OptDBR.

Source: Own work.

2.5 Conclusions and policy recommendations

Using an estimated DSGE model of the Slovenian economy, which is similar to Adolfson et al. (2007) and Masten (2010), this chapter evaluates the cyclical behaviour and welfare effects of five alternative types of fiscal rules: the optimal simple fiscal rule for government consumption (OSR), the balanced budget rule (BBR), the structural balance rule (SBR), the basic debt brake (Swiss) rule (DBR) and the optimal debt brake rule (OptDBR). The first contribution of the chapter is to study the stabilization properties of fiscal rules. In particular, I compare the volatility of macroeconomic variables that are likely to be of concern of government: output growth, government consumption growth, budget balance and public debt. The second contribution of the chapter is to investigate, using historical counter-factual experiment, what would have happened with the above-mentioned macroeconomic variables of the Slovenian economy between 1995-2014 if the government had adopted different fiscal rules, given the structural shocks identified in the baseline DSGE model which assumes no explicit rule for fiscal policy.

Before addressing these two questions, I devoted the first part of the results section to an impulse response analysis which involves comparing the effects of a negative investment shock under alternative fiscal rules in order to better understand the underlying mechanism behind. In particular, I illustrate the dynamics of the output growth, government consumption growth, budget deficit and public debt. These results suggests that when a negative investment shock hits the economy, the government following the BBR and the SBR cuts in its consumption, amplify-ing the negative effect of investment shock on output growth. On the other hand, according to the OSR as well as to the OptDBR, the government provides a fiscal stimulus, in the form of increased consumption, as economic activity deteriorates due to a negative investment shock. The output growth contraction that results is then less severe. The largest increase in government consumption is achieved using the OptDBR, the second largest increase is observed when the government follows the OSR, while under the DBR government consumption practically does not react.

Turning now to the main results of the chapter, the analysis of the macroeconomic stabilization and welfare properties of the fiscal rules shows that the lowest welfare loss is achieved by the OSR, which ties down real government consumption to the economy's output gap, consumer inflation, combined with a deficit and public debt correction mechanism. The optimized feedback coefficients in the simple fiscal rule suggest that for macroeconomic stabilization government should respond more strongly to the output gap and the public debt relative to the consumer inflation and the budget deficit. Further, the OptDBR, which links the expenditure ceiling to the amount of trend revenues and, at the same time, allows for a higher counter-cyclical stance, exhibits the second best performance in terms of welfare loss, while the third best performance belongs to the basic debt brake rule, which relates spending to trend revenues. Predictably, the BBR and SBR, which do not allow for a build-up of public debt and budget deficits during the business cycle, perform the worst in terms of welfare loss, since they tend to reinforce the business cycle, promoting expansion and aggravating recession. There are also other interesting findings that need to be mentioned. In particular, I find that all fiscal rules examined exhibit greater stability of government consumption growth over time, when compared to the pro-cyclical BBR. Furthermore, as regards the volatility of budget balance and public debt, the results show that the worst performance is given by the OptDBR, while the BBR and the SBR have the best performance. Regarding the public debt volatility, it is also found that the DBR can approximate the OSR very well, since the public debt volatility is quite similar under these two rules.

Lastly, based on a historical counter-factual analysis, I show that adopting fiscal rule would have had several beneficial effects on the state of the Slovenian economy in the 1995-2014 period. In particular, the following conclusions can be drawn on the basis of the results obtained: First, I find significantly positive effects of fiscal rules on fiscal outcomes. In particular, during the expansion phase preceding the economic crisis of 2008-2009, the results show that with all fiscal rules budget balance would have been below the path than had occurred under no fiscal rule scenario. In other words, in good times, fiscal rules would have forced the government to restrain domestic demand, which in turn would have helped to reduce the risk of overheating. Together with the increased tax revenues, such policy would have had positive effects on budget balance. By contrast, during the crisis some of these rules (especially the OSR one) would have implied higher deficits compared to their realised counterparts. This is partly the result of lower tax revenues, and partly attributable to the expansionary fiscal policy that would have been adopted to stimulate aggregate demand in order to counteract the negative implications of the economic crisis. The result that is even more interesting is that if the rule-based fiscal policy would have been run during the 1995-2014 period, a much lower public debt would have been achieved compared to its actual path. The low level of public debt would have not only been reflected in lower sovereign risk and reduced costs of finance for economic agents, it would have also decreased the volume of interest payments, which would have indirectly promoted economic growth. Second, in terms of mitigating the severity of the two recent recessions, the OSR and the OptDBR are found to have positive but relatively small effects.

On the basis of the results obtained, this chapter gives some policy recommendations. Empirical evidence shows that Slovenia as well as most Euro area countries run inappropriate fiscal policy before the start of the economic and financial crisis since it was expansionary (procyclical) instead of restrictive as it should be from the theoretical point of view. This prevented accumulation of fiscal surpluses which in turn limited the capacity of fiscal policy to move in a counter-cyclical manner during recessionary periods. In terms of policy recommendations, the results suggest that the fiscal rule should be counter-cyclical by construction in order to contribute to macroeconomic stability without threatening long-term fiscal sustainability. The design of an effective fiscal rule should also take into account the feedback of selected fiscal indicator from accumulated public debt to prevent it from fluctuating excessively. However, rules themselves are insufficient to guarantee fiscal policy counter-cyclicality and sustainability, since they must be accompanied by enforcement mechanisms, transparency improvements in fiscal procedures, and by independent fiscal institutions, such as fiscal councils which should monitor the implementation of the fiscal rule. In addition, fiscal rules should be easy to implement. While some rules are better in delivering best outcomes as per the DSGE results, their implementation may be difficult. For example, based on the results obtained, the optimal fiscal rule is the one that offers the lowest welfare reduction. But this rule is relatively complicated – it involves the calculation of output gap and optimized coefficients, which may be difficult to implement in practice as well as to communicate to the public. For this reason, probably better strategy would be to follow the basic debt brake rule which seems relatively straightforward and easy to understand. In addition, this rule yields a welfare gain and a reduction in volatility similar to that of the more complicated optimal fiscal rule. This is one of the most important findings of the chapter and shows that a good rule need not be complex.

The rules are also not sufficient to overcome structural problems. In the case of Slovenia, the key structural challenges to fiscal policy include (IMAD, 2016): demographic changes and the high level of state ownership in companies, which are the main factors behind the current and expected public debt. In the future, demographic changes due to population ageing will put pressure on the pension, health care and long-term care related expenditures. In addition to that, the run-up in public debt could also be reversed through more efficient management or by continuing the privatisation process of state-owned companies. In order to achieve long-term fiscal sustainability, structural measures aimed at increasing competitiveness and labour market efficiency could also be adopted, which would expand the tax base and increase its quality. In such a situation, adopting a long-term strategy for reducing the existing structural imbalances, incorporating fiscal rule as one of its key elements, would be the best way to ensure sound public finances.

This chapter should be seen as a start of a more in-depth investigation into the rule-based fiscal policy and could be extended in several directions. Further research could concentrate on the various policy instruments (e.g. different tax rates) that could be adjusted to satisfy the fiscal rules. Furthermore, one could specify optimal simple fiscal rules for other policy instruments instead of focusing only on the government consumption. Another potential avenue of future research could be to investigate the interaction of fiscal and monetary policy, and how this would affect the overall results. In this context, one could search for the best combination of monetary and fiscal policy actions when the economy is hit by different shocks. It would also be interesting to extend the model to make government spending useful (instead of treating it as wasteful) either by allowing for households to enjoy utility directly from the consumption of public goods, or by letting government spending enhance productivity. In the future, fiscal variables could also be used to estimate the model. I leave these extensions for future work.

3 ELECTRICITY IN A DSGE MODEL SETTING[57]

3.1 Introduction

Electricity is considered as one of the most important energy source in the economy. It is used in a wide variety of fields that affect our lives. Because of its important role in the functioning of the economy and the life of the population, the change of its price raises questions about the macroeconomic and microeconomic effects. In order to ensure efficient electricity power transmission through a transmission network it is also of particular importance for electricity producing firms to know the economic effects of the price changes of different components that make up the final electricity price.

The effects of energy prices on macroeconomic activity have always been an area for research for the economists, but the literature for a particular case of electricity prices is scarce since the literature typically focuses on oil price shocks (see e.g. Kilian, 2008; 2009; Peersmann & Van Robays, 2009; Medina & Soto, 2005; among many others). In order to fill this gap, we develop a DSGE model with electricity for the Slovenian economy. The model was developed as part of a research project for practical uses at a company operating in the electricity sector. The model's structure is similar to that in Adolfson et al. (2007) and Masten (2010), with one notable difference - electricity is explicitly included in the consumption basket and also in the production technology used by domestic firms. This required several modifications to these baseline models. Such a framework seems particularly appropriate for companies operating in the electricity sector. It is crucial for these companies to know the impact of possible changes in electricity prices on main economic indicators (e.g. the GDP, electricity demand and others) since these affect management decisions in a number of areas, including transmission network planning, revenue calculations and many others (Rhys, 1984). This necessitates the use of macroeconomic models that can be useful for the support of decision making.

In general, the model allows the assessment of the price changes of electricity price components such as the price of energy, price for the use of the network, contributions and the excise duties on electricity, on key macroeconomic variables, including public finance. It is also possible to quantify the impact of electricity price changes on household and industrial electric energy consumption. General parameter values are calibrated to the same values as in the first chapter of the dissertation, while the electricity related parameters are calibrated using data on Slovenian

[57]This chapter is joint work with Igor Masten.

electricity market. Using impulse response analysis, the dynamic properties of the developed model are illustrated by considering the macroeconomic responses following of some hypothetical scenarios involving price changes in the electricity price components. In this regard, the main research question in this chapter is what are the effects of electricity price shocks on the Slovenian economy?

The contribution in this chapter is threefold: From a methodological point of view, this chapter develops an analytical framework based on a DSGE model that is suitable for carrying out electricity sector related analyses. This is to the best of our knowledge the first attempt to incorporate electricity in a DSGE model that reflects specific features of the Slovenian electricity market. Empirical contribution arises from the assessment of the effects of electricity price changes on the Slovenian economy. And lastly, practical contribution of this chapter is that it sets up the model that could be used for practical purposes inside companies operating in the electricity sector. Our study thus responds to the request made by one of these companies for the development and calibration of the model for Slovenia in order to enable company's staff to perform electricity sector related scenarios on their own after having received appropriate training.

The chapter is structured as follows: Our DSGE model augmented with electricity prices elements is presented in Section 3.2. Section 3.3 describes the calibration with special attention given to the calibration of electricity sector related parameters. Section 3.4 defines and discusses results of some hypothetical scenarios involving price changes in the electricity price components. Section 3.5 concludes.

3.2 The DSGE model

The model considered in this chapter is a medium-scale DSGE model of a small open economy presented in Adolfson et al. (2007) and Masten (2010). Our contribution to the existing models is made in the context of electricity price shocks modelling. Electricity enters in our model as a consumption good for households and as a production input for domestic firms. This required several modifications to the baseline model, presented in Chapter 1. Since the model structure apart from the electricity price elements is identical to that described in Chapter 1, this chapter provides an overview of the model structure with focus on the relevant aspects of the electricity price elements.

3.2.1 Aggregate supply

The domestic firms uses labour together with capital and electricity input to produce intermediate goods Y_i, which are sold to the final good producer. The production function of the final good firm is of the Dixit-Stiglitz form. The final good producers operate in a perfectly competitive environment, taking the prices of the intermediate goods $P^d_{i,t}$ and final goods P^d_t as given. The production function for each intermediate-good firm i which operates under monopolistic competition is of the Cobb-Douglas type and can be expressed as:

$$Y_{i,t}^d = z_t^{1-\alpha}\epsilon_t K_{i,t}^{\alpha(1-\delta_e)}\left(E_{i,t}^d\right)^{\alpha\delta_e} H_{i,t}^{1-\alpha} - z_t\phi, \tag{84}$$

where $H_{i,t}$ denotes homogeneous labour input hired by firm i, $K_{i,t}$ is amount of capital services used by firm i which can differ from capital stock since the model assumes variable capital utilization rate and $E_{i,t}^d$ is the electricity input used in production. Further, z_t is permanent technology shock, while ϵ_t is stationary technology shock. The term $z_t\phi$ indicates fixed costs which grows with technology rate. Fixed costs are set in such a way that profits are zero in steady state. Cost minimization yields the following nominal marginal cost function for intermediate firm i:

$$MC_t^d = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha(1-\delta_e)}\right)^{\alpha(1-\delta_e)}\left(\frac{1}{\alpha\delta_e}\right)^{\alpha\delta_e}\left(R_t^k\right)^{\alpha(1-\delta_e)}\left(P_t^{e,d}\right)^{\alpha\delta_e}$$
$$\left[W_t\left(1+\nu\left(R_{t-1}-1\right)\right)\right]^{1-\alpha}\frac{1}{z_t^{1-\alpha}}\frac{1}{\epsilon_t}, \tag{85}$$

where R_t^k is the gross nominal rental rate per unit of capital, R_t is the gross nominal interest rate, W_t is the nominal wage rate per unit of aggregate, homogeneous labour $H_{i,t}$, and $P_t^{e,d}$ is the electricity price for industrial consumers. The real marginal cost function scaled by z_t is given by:

$$mc_t^d = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha(1-\delta_e)}\right)^{\alpha(1-\delta_e)}\left(\frac{1}{\alpha\delta_e}\right)^{\alpha\delta_e}\left(r_t^k\right)^{\alpha(1-\delta_e)}\left(\gamma_t^{ed,d}\right)^{\alpha\delta_e}$$
$$\left[w_t\left(1+\nu\left(R_{t-1}-1\right)\right)\right]^{1-\alpha}\frac{1}{\epsilon_t}, \tag{86}$$

where the following definitions are used:

$$mc_t^d \equiv \frac{MC_t^d}{P_t^d z_t}, \quad r_t^k \equiv \frac{R_t^k}{P_t^d}, \quad w_t \equiv \frac{W_t}{P_t^d z_t}, \quad \gamma_t^{ed,d} \equiv \frac{P_t^{e,d}}{P_t^d}. \tag{87}$$

Besides solving the cost minimization problem, intermediate good firms decide on price for their output. Prices are set subject to a Calvo (1983) price-setting mechanism combined with partial indexation to the previous periods inflation rate for those firms that do not receive a Calvo signal in a given period. This results in a hybrid new Keynesian Phillips curve.

3.2.2 Aggregate demand

Households attain utility from consumption and leisure. The households decide on their current level of consumption and their domestic and foreign bond holdings. They also choose the level of capital services provided to the firms, their level of investment and their capital utilization rate. The households can increase their capital stock by investing in additional physical capital, taking one period to come in action, or by directly increasing the utilization rate of the capital at hand. The j^{th} household's utility function is:

$$\mathbb{E}_0^j\sum_{t=0}^{\infty}\beta^t\left[\zeta_t^c\ln\left(C_{j,t}-bC_{j,t-1}\right)-\zeta_t^L A_L\frac{\left(h_{j,t}\right)^{1+\sigma_L}}{1+\sigma_L}\right], \tag{88}$$

where $C_{j,t}$ and $h_{j,t}$ denotes levels of real consumption and labour supply of household j, respectively. The model also allows for habit formation in consumption by including $bC_{j,t-1}$. ζ_t^c and ζ_t^L are preference shocks, consumption preference shock and labour supply shock, respectively. The aggregate consumption C_t is specified as a Cobb-Douglas utility function:

$$C_t = (C_t^z)^{1-\omega_e} (C_t^e)^{\omega_e}, \tag{89}$$

being composed of electricity consumption for household consumers C_t^e as well as bundle of non-electricity consumption (core consumption) C_t^z. Parameter ω_e is the share of electricity consumption in overall consumption. The consumer price index (CPI) is given by:

$$P_t^c = (P_t^z)^{1-\omega_e} (P_t^{e,c})^{\omega_e}, \tag{90}$$

where P_t^z denotes the core consumption price index which excludes the price of electricity and $P_t^{e,c}$ is the electricity price for household consumers. The core consumption is a CES index of domestic and imported consumption goods:

$$C_t^z = \left[(1-\omega_c)^{1/\eta_c} \left(C_t^d\right)^{(\eta_c-1)/\eta_c} + \omega_c^{1/\eta_c} \left(C_t^m\right)^{(\eta_c-1)/\eta_c}\right]^{\eta_c/(\eta_c-1)}. \tag{91}$$

C_t^d and C_t^m are consumption indices of domestic and imported consumption goods, respectively, ω_c is the share of imported consumption goods in total consumption, and η_c is elasticity of substitution between domestic and imported consumption goods. The corresponding core consumption price index which excludes the price of electricity is given by:

$$P_t^z = \left[(1-\omega_c)^{1/\eta_c} \left(P_t^d\right)^{1-\eta_c} + \omega_c^{1/\eta_c} \left(P_t^{m,c}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)}. \tag{92}$$

The demands for electricity and core consumption are given by:

$$C_t^z = (1-\omega_e)\left[\frac{P_t^c}{P_t^z}\right] C_t \tag{93}$$

$$C_t^e = \omega_e \left[\frac{P_t^c}{P_t^e}\right] C_t, \tag{94}$$

while the demand functions for domestic and imported consumption goods are as follows (Obstfeld & Rogoff, 1996):

$$C_t^d = (1-\omega_c)\left[\frac{P_t}{P_t^z}\right]^{-\eta_c} C_t^z \tag{95}$$

$$C_t^m = \omega_c \left[\frac{P_t^{m,c}}{P_t^z}\right]^{-\eta_c} C_t^z. \tag{96}$$

The model also assumes that households can purchase investment goods in order to increase their capital stock. Furthermore, the model accounts for monopolistic competition in labour supply and Calvo-type rigidity in nominal wages in line with Erceg et al. (2000) and Christiano et al. (2005).

3.2.3 Foreign sector

In addition to domestic firms, there are also importing and exporting firms present in the model. Importing firms buy a homogeneous consumption and investment good in the foreign market and differentiate it to sell it in the domestic market. Similarly, exporting firms buy the homogeneous final consumption good produced in the domestic economy and differentiate it to sell it abroad. The differentiated investment and consumption import goods are further aggregated in a second step via a CES function, respectively. The same applies to the export goods. The model assumes monopolistic competition among importers and exporters and Calvo type staggered price setting, allowing for incomplete exchange rate pass-through in the short run. The foreign economy is described by an identified VAR model containing foreign prices, foreign output and foreign interest rate.

3.2.4 Public sector

Government expenditure is split between consumption, transfers to households and interest on outstanding debt. Expenditure is financed through taxes (on consumption, capital, and labour income) and new debt. The government budget constraint therefore can be written as:

$$B_{t+1} + T_t = R_{t-1}B_t + TR_t + P_t^d G_t \Leftrightarrow B_{t+1} = B_t + DEF_t. \tag{97}$$

The total tax revenue is defined by:

$$\begin{aligned} T_t \;=\; & \tau^c P_t^c C_t + \tau^y W_t H_t + T_t^{excise} \\ & + \tau^k \left[\left(R_{t-1} - 1\right) B_t + R_t^k K_t + \left(R_{t-1}^* \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right) - 1 \right) B_t^* + \Pi_t \right]. \end{aligned} \tag{98}$$

The excise duty on electricity T_t^{excise} is defined as:

$$T_t^{excise} = \tau_t^{excise} Y_t^{d,e}. \tag{99}$$

Further, the government expenditures are given by:

$$GEX_t = TR_t + G_t + \left(R_{t-1} - 1\right) PD_{t-1}, \tag{100}$$

where TR_t denotes transfers to households, G_t is government consumption of goods and services and $\left(R_{t-1} - 1\right) PD_{t-1}$ stands for public debt interest payments. To avoid the explosive debt path, the following simple fiscal rule for government consumption is imposed (in log-linear terms):

$$\hat{g}_t = \rho_g \hat{g}_{t-1} - \phi_b \hat{b}_{t-1} + \varepsilon_{g,t}. \tag{101}$$

3.2.5 Market equilibrium

In equilibrium all markets clear. The equilibrium on the final good market is given by:

$$C_t^d + I_t^d + G_t + C_t^x + I_t^x \leq z_t^{1-\alpha} \epsilon_t K_t^{\alpha(1-\delta_e)} \left(E_t^d\right)^{\alpha\delta_e} H_t^{1-\alpha} - z_t \phi - a\left(u_t\right) \bar{K}_t, \tag{102}$$

where C_t^x and I_t^x are the foreign demand for export goods which follow CES aggregates with elasticity η_f. Further, the net foreign assets' market clears when domestic investment in foreign bonds (denoted by B_t^*) equals the net position of exporting/importing firms:

$$B_t^* = P_t^x \left(C_t^x + I_t^x\right) - P_t^* \left(C_t^m + I_t^m\right) + R_{t-1}^* \Phi\left(a_t, \tilde{\phi}_t\right) B_t^*, \tag{103}$$

where $R_{t-1}^* \Phi\left(a_t, \tilde{\phi}_t\right)$ denotes the risk-adjusted gross nominal interest rate, and definition of a_t is given by:

$$a_t \equiv \frac{B_{t+1}^*}{P_t^d z_t}.$$

The market clearing condition in the electricity market reads as:

$$Y_t^{d,e} = C_t^e + E_t^d = Y_t^{s,e} + M_t^e, \tag{104}$$

where $Y_t^{s,e}$ represents the domestically produced electricity and M_t^e denotes the imported electricity. Finally, the total GDP identity is given by:

$$Y_t = Y_t^d + Y_t^{s,e}. \tag{105}$$

3.3 Calibration and estimation

In order to set up model simulations, we need to specify the values of the parameters. In general, model parameters can be divided into two main subgroups according to the way we set their values: general model parameters which are either picked from the existing DSGE literature or estimated using Bayesian approach, and electricity sector related parameters. The latter are calibrated using data on Slovenian electricity market. Since the estimation procedure and the calibration of general model parameters have been presented in great detail in the first chapter of the dissertation, we only limit our attention to a description of the calibration features of electricity sector related parameters here. Because the nonlinear system as described above cannot be solved analytically, we log-linearized the model equations[58] around the non-stochastic steady state[59].

3.3.1 Calibration of electricity sector related parameters

Calibration of equilibrium share parameters. In performing model simulations, it is necessary to determine the share of costs that electricity represents in total value added of the economy. We have done this by using data sets which contain information about energy costs from the balance sheets of companies, collected by AJPES. According to these data, the share of energy in the value added by enterprises was 9.8 % during the 2002-2012 period. The share had increased over the period, reaching 12.4 % in 2012. It should be noted that these costs are related to all energy

[58]The log-linearized versions of these equations are reported in Appendix O.

[59]Appendix N presents the steady-state of the model.

sources, of which electricity represents a part. We estimate that this share is about 6 % of total value added. On the demand side, it is necessary to determine the share of electricity in the final consumption basket. According to the Statistical Office of the Republic of Slovenia (SORS), this share amounted to 3.8 % in 2013. To perform model simulations, it is also necessary to determine the share of household consumption (0.33) and the share of domestically produced electricity (0.7).

Calibration of price elasticity of supply and demand. In calibrating the model, we paid special attention to the specification of electricity supply. The DSGE model is intended for a short- and medium-term economic analysis, i.e. for explaining macroeconomic dynamics at the business cycle frequency. We have assumed that electricity production capacities are given at business cycle frequency and are high enough to meet fluctuations in demand. We can justify this in three ways. The first is the nature of investment in electricity production, which is extensive, planned over a long period and lasts a long period of time, with changes subject to the assessment of state authorities. Second, Slovenia is part of a relaxed European market, sufficient transmission capacity is set up at state borders and the import of electricity fluctuates with demand at given stock prices. Most of the electricity imported to Slovenia comes across the Austrian border. The physical share of imported electricity is the parameter that needs to be calibrated in the model, although it does not have a significant effect on macroeconomic dynamics. In the past, approximately one third of domestic electricity consumption was satisfied by imports. We assume that domestic electricity production is completely elastic within certain relative price ranges, which includes turning on the generation capacity network. This means, for example, that at a lower price range, supply by hydroelectric and nuclear power plants is fully activated, while at higher price ranges, thermal production is activated. It may be reasonably assumed that the user of the model can accurately predict the share of total electricity production in a certain price range, given knowledge of electricity production capacities. The income elasticity of demand for electricity is determined on the basis of structural connections in the model. As can be seen from the simulations, the demand for electricity fluctuates with economic activity. The correlation is weak in the short run, but strong in the long run. The price elasticity of demand is calibrated using the Liu (2004) study, which contains estimates of the elasticity of demand for OECD countries. The study estimates the short-term elasticity of household demand to -0.03. The short-term elasticity of demand for firms is lower and amounts to -0.015. From the estimates, it is clear that the demand for electricity is price inelastic.

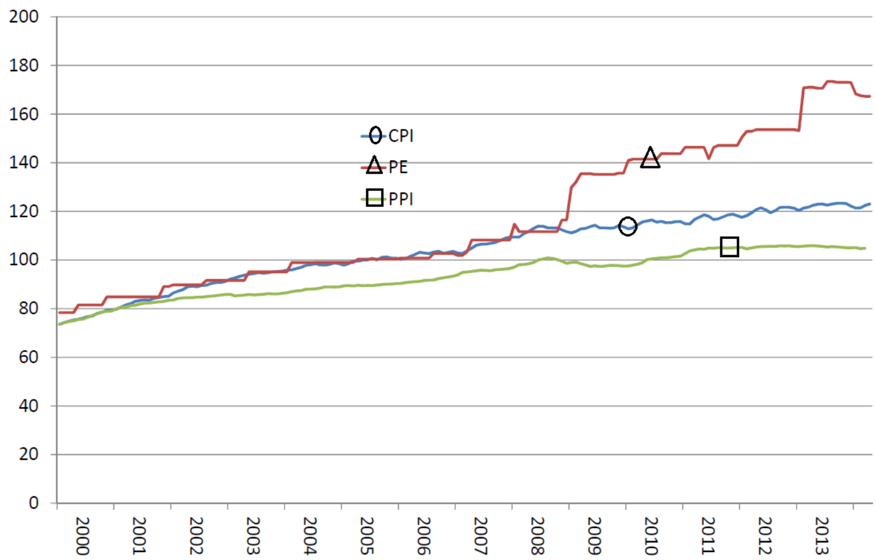
Calibration of electricity price structure. The retail price of electricity consists of the price of energy (wholesale price), the network usage fee, various contributions, excise duty and value added tax. Value added tax is proportional and does not pose a challenge. The other components are expressed as fixed values per unit of energy consumed, so in the model it is necessary to calibrate their shares in the final retail price (before VAT). For the purpose of simulations, this is done on the basis of data from 2012. The domestic wholesale price of energy is also affected by the cost of cross-border transmission capacities. The impact of this cost on market price is not determined within the model, but needs to be determined by the user as an input for the simulation.

Parametrisation of electricity prices process. In the model, it is also necessary to define the equations for determining the wholesale energy price. Since the historical time series of wholesale electricity price are not available at high frequencies (at least quarterly), we use retail prices when analysing the properties of the price process. Figure (4) shows the movement in the consumer price index, the producer price index and the retail electricity price index. The figure shows that the price divergence is mainly driven by significant price jumps, resulting from jumps in contributions (January 2009 and February 2013). Such jumps are predictable, as they are usually explicitly announced either by the Republic of Slovenia or the Energy Agency of the Republic of Slovenia. From Figure (5) it can be seen that discrete jumps of electricity price due to movements in contributions, cause permanent and persistent changes in relative electricity prices, i.e. electricity prices relative to the CPI or PPI. In order to capture empirical regularities in price modelling, we estimated the following model:

$$\pi_t^{e,c} = \alpha_e \pi_{t-1}^{e,c} - \alpha_\gamma \gamma_{t-1}^{ec,d} + \varepsilon_t^{ec,d}, \tag{106}$$

where $\pi_t^{e,c}$ represents the monthly growth rate of electricity prices for households, as reported by SORS, $\gamma_{t-1}^{ec,d} \equiv \ln\left(P_t^{e,c}\right) - \ln\left(P_t^d\right)$ is the relative price of electricity relative to the producer price index (P_t^d). Such a process is assumed in the model for both the electricity prices for households as well as for firms (hereinafter referred to as $P_t^{e,d}$), which is reasonable given the fact that the majority of short-term variations in prices come as a result of changes in the wholesale price of energy.

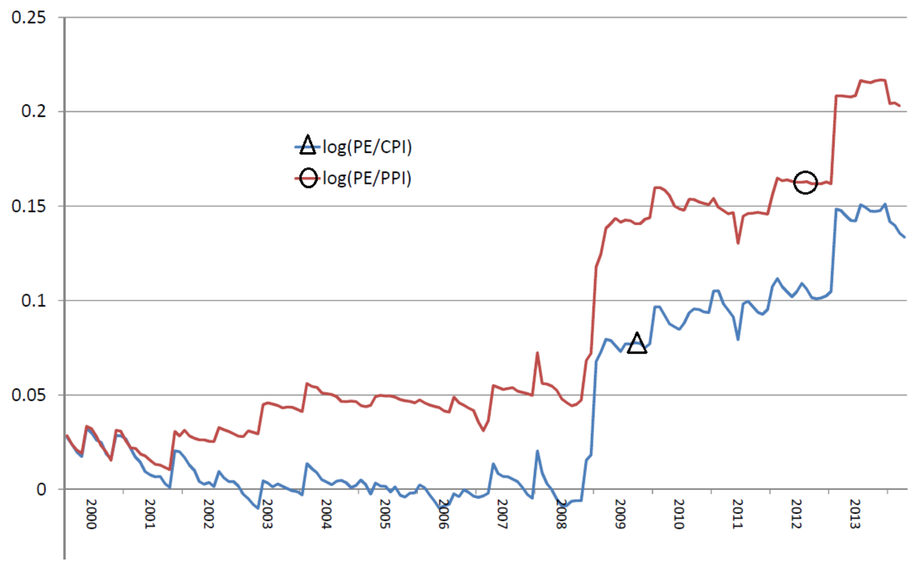
Figure 4: *Historical electricity prices for household consumers (PE), consumer price index (CPI) and producer price index (PPI)*



Source: SiStat Statistical Database.

The model given by (106) is a simple error correction model. It is assumed that electricity price inflation follows the autoregressive process, but to some extent, through the coefficient α_γ, it responds to the deviations of these prices from other prices in the economy. In this way we capture the fact of low but existing elasticity of substitution between electricity and others goods in the economy. The model is estimated on the basis of monthly data for the period of January 2000 to March 2014, which means that we have 170 observations. Our sample is large enough given that we are estimating only two parameters. Estimates are obtained by use of the OLS method to deliver consistent parameter estimates under the condition that errors of the model $\varepsilon_t^{ec,d}$ are not autocorrelated. This can also be verified by using the LM test for autocorrelation of the residuals of the model. A p test for fourth order autocorrelation takes the value of 0.21. The estimates of the model parameters are as follows: the parameter α_e takes a value of -0.02 and is statistically insignificantly different from zero. The estimate of parameter α_γ is -0.01 and is found to be statistically significant at 10 %.

Figure 5: *Historical relative electricity prices for household consumers*



Source: SiStat Statistical Database.

3.3.2 Modelling electricity price shocks

This subsection describes a modelling approach of electricity price shocks. The model distinguishes between the final electricity price for household consumers and final electricity price for industrial consumers. In general, the final electricity price for each type of consumers consists of: the price of energy, the use-of-network price, including the network charge and the supplements to the network charge, the contributions, the excise duty on electricity, and the value-added tax. It is worth noting that the excise duty on electricity is the same for household and industrial consumers while the other price components are applied at different rates. Further, the model assumes that the electricity price inflation for household consumers $\hat{\pi}_t^{e,c}$ is given by the following process (expressed in log-linearized terms):

$$\hat{\pi}_t^{e,c} = \alpha_e \hat{\pi}_{t-1}^{e,c} - \alpha_\gamma \hat{\gamma}_{t-1}^{ec,d} + \varepsilon_t^{ec,d},$$

while the electricity price inflation for industrial consumers $\hat{\pi}_t^{e,d}$ is defined as:

$$\hat{\pi}_t^{e,d} = \alpha_e \hat{\pi}_{t-1}^{e,d} - \alpha_\gamma \hat{\gamma}_{t-1}^{ed,d} + \varepsilon_t^{ed,d}.$$

$\varepsilon_t^{ec,d}$ and $\varepsilon_t^{ed,d}$ are exogenous disturbances which are defined as follows:

$$\varepsilon_t^{ec,d} = \omega_{ec1}\varepsilon_{\text{price},t}^{e,c} + \omega_{ec2}\varepsilon_{\text{network},t}^{e,c} + \omega_{ec3}\varepsilon_{\text{contributions},t}^{e,c} + \omega_{ec4}\varepsilon_{\text{excise},t} \tag{107}$$

$$\varepsilon_t^{ed,d} = \omega_{ed1}\varepsilon_{\text{price},t}^{e,d} + \omega_{ed2}\varepsilon_{\text{network},t}^{e,d} + \omega_{ed3}\varepsilon_{\text{contributions},t}^{e,d} + \omega_{ed4}\varepsilon_{\text{excise},t}. \tag{108}$$

Parameters ω_{ec} and ω_{ed} represent the share of specific price component in the final electricity price for household consumers and industrial consumers, respectively. The electricity price changes are induced in the model in such a way that we change $\varepsilon_t^{ec,d}$ and $\varepsilon_t^{ed,d}$ according to a certain scenario. Table (10) summarizes possible exogenous changes to the electricity price components.

Table 10: *Possible exogenous changes to the electricity price components*

$\varepsilon_{\text{price},t}$	Price of energy
$\varepsilon^{e,c}_{\text{network},t}$	Network costs for household consumers
$\varepsilon^{e,c}_{\text{contributions},t}$	Contributions for household consumers
$\varepsilon_{\text{excise},t}$	Excise
$\varepsilon^{e,d}_{\text{network},t}$	Network costs for industrial consumers
$\varepsilon^{e,d}_{\text{contributions},t}$	Contributions for industrial consumers

Source: Own work.

3.4 Simulation properties of the model

There are four potential sources of exogenous shocks to the final electricity price: the price of energy, the use-of-network price, the contributions and the excise duty on electricity. In this section we present the results of some possible simulation scenarios through the impulse response functions.[60] In particular, we concentrate our analysis on the price of energy. Of course, several other simulations are possible, involving the other components of the final electricity price. The end result varies depending on the share each component represents in the final electricity price (see Table (11)).

Table 11: *Shares of different components in the final electricity price*

	Households	Industry
Energy	0.45	0.61
Network	0.42	0.27
Contributions	0.11	0.09
Excise	0.02	0.04

Source: Electrical Energy - Prices.

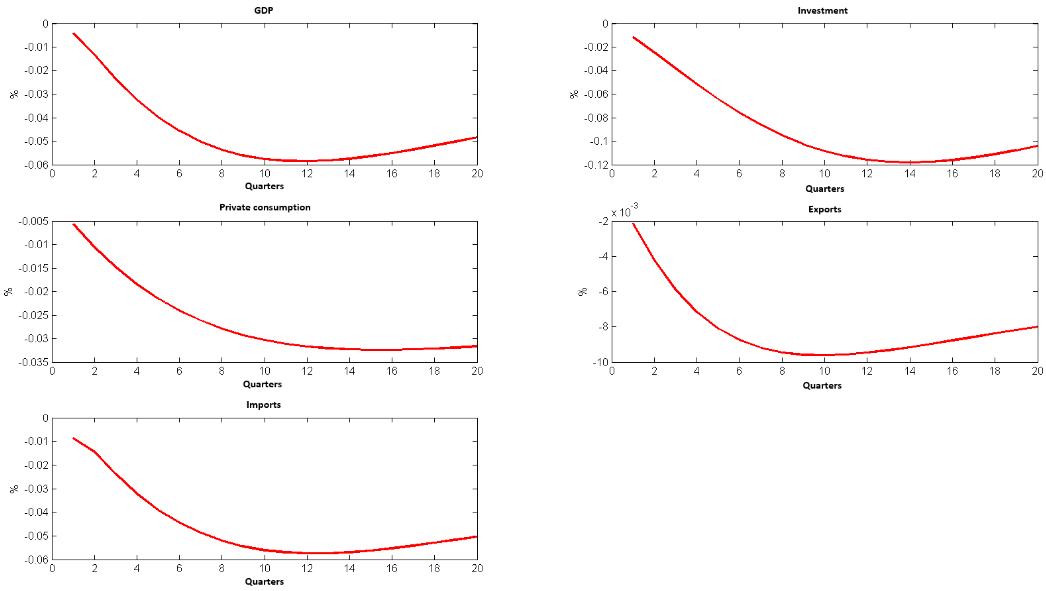
First, we look at the basic simulation scenario, namely the effects of a 1 % increase of wholesale electricity prices on macroeconomic variables. For example, this can happen due to the increase in the cost of cross-border transmission capacities. The cost increase is long-lasting and produces a very persistent impact on prices, which means that the subsequent endogenous adjustment of retail prices is, according to the structural equations of the model, relatively slow. The results are shown in Figures (6)-(8), which depict the so-called impulse responses of variables, where

[60] To facilitate the user to work with the model, graphical interface was developed. See Appendix P.

the impulse represents an exogenous price change in electricity (in the wholesale market), and the responses are the changes of the selected macroeconomic variables of the model. Figure (6) shows the responses of key macroeconomic aggregates, from GDP to imports. Figure (7) shows the responses of budget revenues while Figure (8) depicts responses of the electricity consumption, inflation, real marginal costs and the growth rate of retail electricity prices. The impulse response analysis shows the following: Electricity is an important production input and consumption good in the economy. This means that its price increases affects both the final price as well as the cost of the economy (see the marginal cost response in Figure (8)). Therefore, exogenous price increases have stagflationary effects on the economy. At the same time, one can observe a short-term increase in inflation by about 0.02 p. p. (Figure (8)) and a decrease in economic activity (Figure (6)). Reduction of GDP, which should be understood as a deviation from trend growth, reaches its peak at around 0.06 p. p. 3 years after the initial change in prices has occurred and then only gradually returns back to equilibrium. The effect is somewhat stronger on investments (decrease by 0.12 p. p.), while it is less severe on private consumption. After 2.5 years, exports decline by 0.01 p. p. (higher production costs reduce the competitiveness of the economy), and the decline in imports closely follows the dynamics of GDP. The impact on the general government sector is also negative. Only VAT is increased for a short time (higher price multiplied by the VAT rate), later on, when the adjustment of private consumption occurs, VAT receipts fall.[61] All other forms of taxes also decline. The final result is an increase of budget deficit, which peaks at 0.02 p. p. of GDP around 2.5 years after the shock.

[61] An increase in the price of electricity would result from the increase in contributions or excise duties that can be understood as an inflow into the state budget, this would further strengthen budget revenues in the short term.

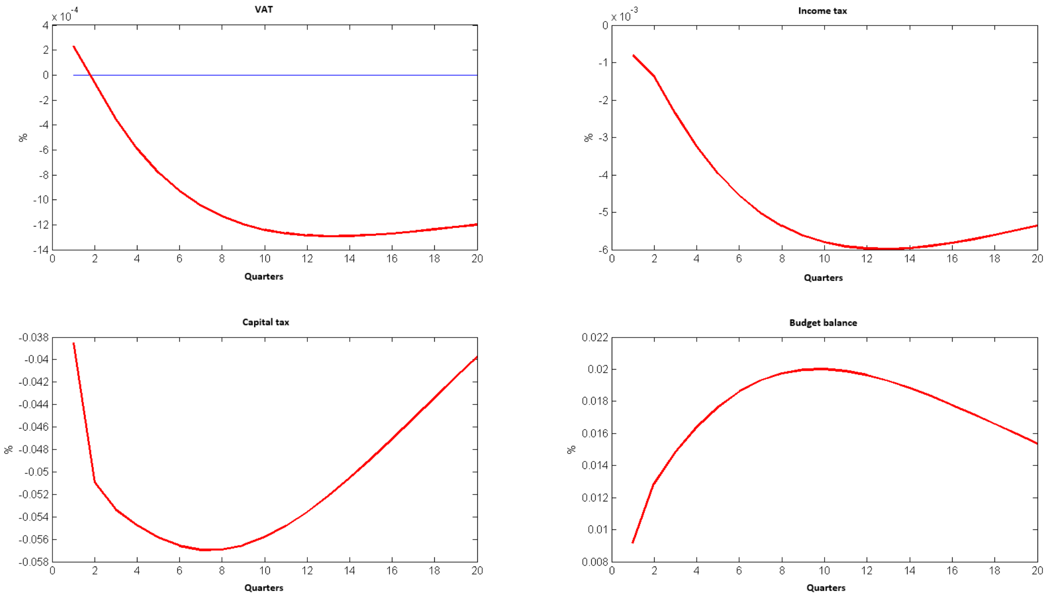
Figure 6: *Impulse responses to a 1 % permanent increase in wholesale electricity prices - effects on main macroeconomic aggregates*



Notes: Each plot displays percent deviation from steady state of corresponding variable. The impulse horizon is measured in quarters.

Source: Own work.

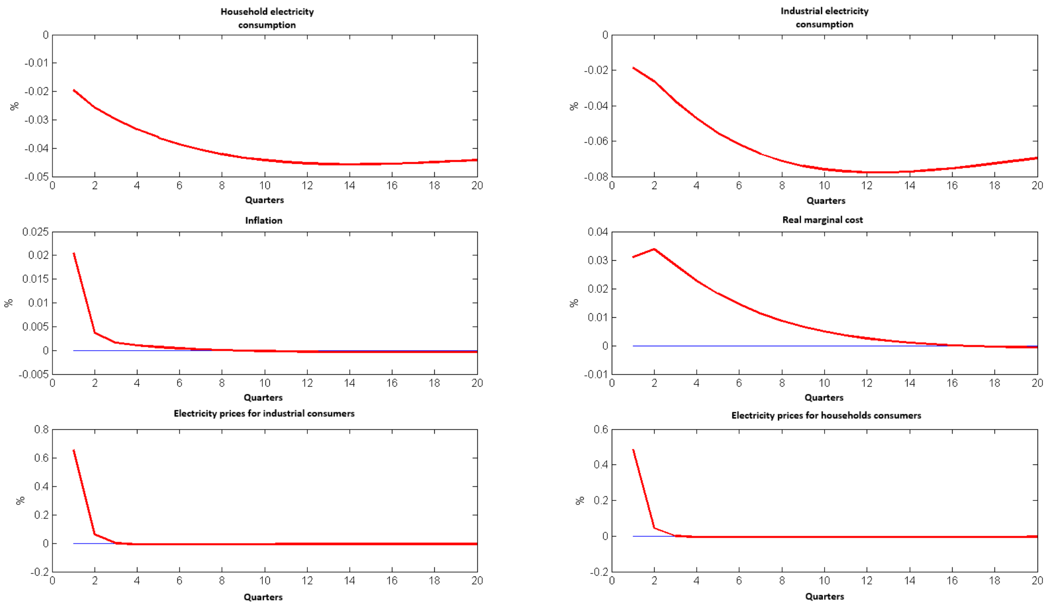
Figure 7: *Impulse responses to a 1 % permanent increase in wholesale electricity prices - effects on state budget*



Notes: Each plot displays percent deviation from steady state of corresponding variable. The impulse horizon is measured in quarters.

Source: Own work.

Figure 8: *Impulse responses to a 1 % permanent increase in wholesale electricity prices - effects on inflation and electricity consumption*

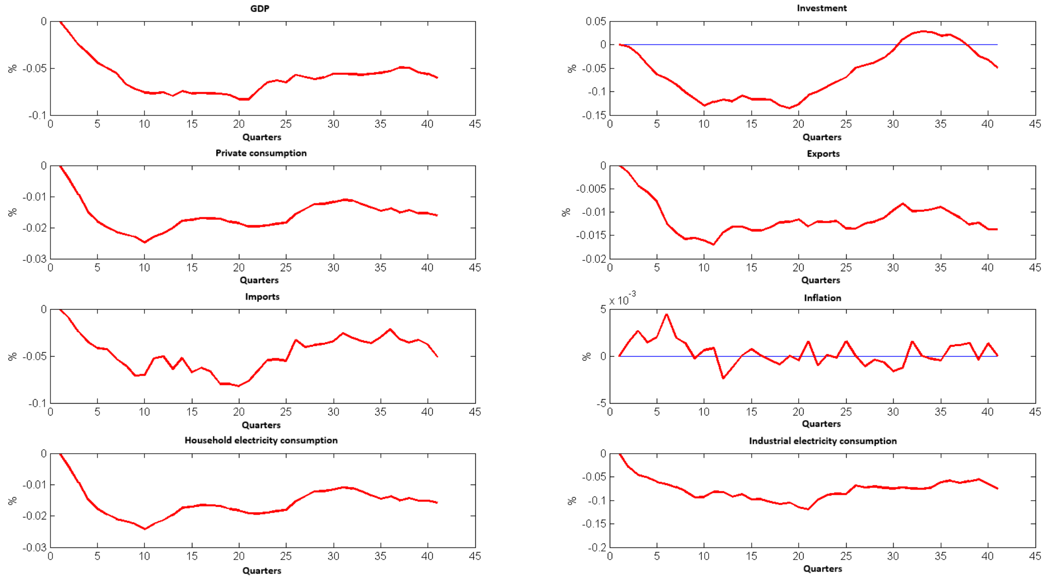


Notes: Each plot displays percent deviation from steady state of corresponding variable. The impulse horizon is measured in quarters.

Source: Own work.

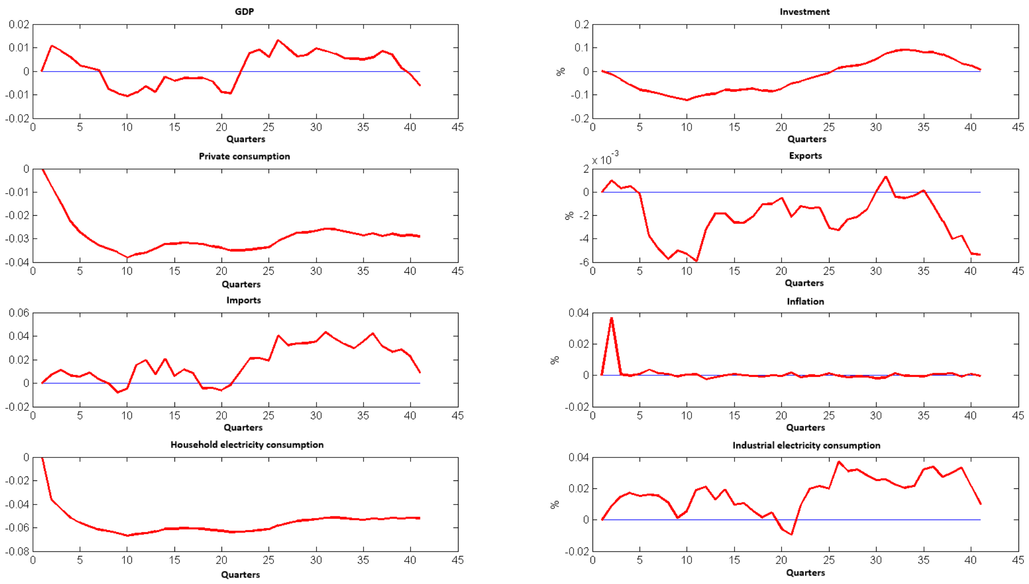
Electricity enters the model both as a consumption good and as an input to production. From this point of view, the model allows us to investigate the effects of partial price increases, namely a separate increase in electricity price for household and a separate increase for industrial consumers. In the following, we are showing only the effects on key macroeconomic aggregates, i.e. the GDP components and inflation. Figure (9) shows the price increase for industrial consumers while Figure (10) shows price increases for household consumers. In both cases, we simulate a 1 % increase in electricity price, which occurs in one quarter, while later on there are no further changes. The results show that an increase in electricity price for industrial consumers has a greater negative effect on economic activity. It causes unambiguous negative effects on GDP, which are more persistent and in absolute terms, at the point of maximum negative impact, eight times bigger. Similar is true for investments, exports and imports. The only exception is private consumption, since in this case an increase in electricity prices for household consumers has greater negative impact. Since an increase in electricity price for industrial consumers has a persistent negative impact on operating costs, the impact on inflation is stronger and more prolonged. We can observe that electricity price shocks have a typical stagflationary effects.

Figure 9: *Impulse responses to a 1 % permanent increase in electricity prices for industrial consumers - effects on main macroeconomic aggregates and electricity consumption*



Notes: Each plot displays percent deviation from steady state of corresponding variable. The impulse horizon is measured in quarters.
Source: Own work.

Figure 10: *Impulse responses to a 1 % permanent increase in electricity prices for household consumers - effects on main macroeconomic aggregates and electricity consumption*

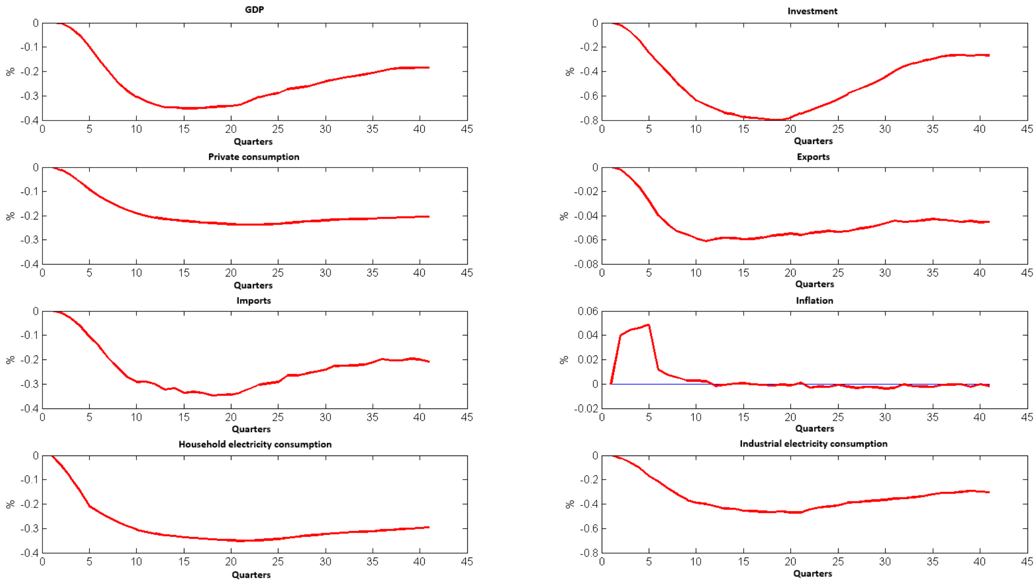


Notes: Each plot displays percent deviation from steady state of corresponding variable. The impulse horizon is measured in quarters.

Source: Own work.

As a last example of the simulation, we look at a slightly more significant change in electricity prices. We simulate the growth of retail prices by 1 % per quarter within a one-year horizon, i.e. 4 quarters. Cumulatively, prices rise by more than 4 %. Higher prices, according to the estimated process of electricity price dynamics, only gradually and over a long period return back to equilibrium. The results of simulation are depicted in Figure (11). The figure shows that price increases have a significant effect on economic activity. After 3-4 years, GDP declines by approximately 0.35 %. This means around 140 million EUR lower value added at an annual level. It can also be seen that GDP only gradually returns back to its equilibrium. After 10 years, it is still 0.2 % below the equilibrium. There are also negative effects on other GDP components. After 4-5 years, investment declines by 0.8 %. Dynamics similar to those of GDP can also be observed for imports and private consumption (the fall is somewhat lower, but more persistent). The smallest effect is on exports, which declines by less than 0.1 %. Two years after the shock inflation rises moderately. The increase in inflation is greater than the share of electricity in the CPI, which means that price pressures also come from the higher costs of firms. Electricity consumption is lower, which is to a large extent driven by lower economic activity. Industrial consumption is thus 0.4 % lower in 3-4 years, while the decrease in household consumption is somewhat smaller (0.35 %) but much more persistent.

Figure 11: *Impulse responses to a 4 % permanent increase (within a one-year horizon) in electricity prices - effects on main macroeconomic aggregates and electricity consumption*



Notes: Each plot displays percent deviation from steady state of corresponding variable. The impulse horizon is measured in quarters.

Source: Own work.

3.5 Conclusion

The main objective of this chapter was to develop a DSGE model with electricity, estimated and calibrated for the Slovenian economy. In addition, the chapter presents the simulation properties of the model. We use a DSGE model of Adolfson et al. (2007) and Masten (2010) and extend their structure with electricity price elements. More specifically, we include electricity in the consumption basket and also in the production function of domestic firms. The parameters of the model are partly estimated by Bayesian methods on quarterly Slovenian macroeconomic data over the period 1995-2014. The remaining parameters, which mostly pertain to the electricity block of the model are calibrated using the data on Slovenian electricity market. Using impulse response analysis, the dynamic properties of the developed model are illustrated by considering the macroeconomic responses following of some hypothetical scenarios involving price changes in the electricity price components. Overall, we find our proposed model well suited for performing electricity sector related analyses. Nevertheless, a limitation of this model and the areas for future research need to be acknowledged. One of the limitations of the developed model is that electricity is the only energy source included in the model. As a consequence, it is possible that the results might slightly overestimate the impact on economic indicators since economic agents cannot substitute electricity with other energy sources. In terms of future work, it would also be interesting to include the electricity generating sector into the existing model. We leave these extensions for future maintenance and development of the model.

CONCLUSION

The main purpose of this doctoral dissertation was to present an estimated medium-scale DSGE model for the Slovenian economy and illustrate some of its applications. In this concluding chapter, I summarize main findings of the dissertation and present contributions and opportunities for future research.

Summary of the main findings

This chapter presents summary of the main findings of the dissertation.

In the first chapter, I estimated the medium-scale small open-economy DSGE model in order to disentangle the contribution of individual structural shocks to macroeconomic developments in Slovenia during the 1995-2014 period, with a particular attention given to the periods of crisis. The results suggest that the investment-specific technology shocks mostly accounted for a significant portion of drop in output growth from 2008 onwards. This result accords with a drop in foreign and domestic orders followed by a decline in investment (mostly at the beginning of the crisis) and the large amount of losses of the corporate sector that accumulated on balance sheets of the banks in the form of non-performing bad loans, further contributing to a contraction of lending activity which in turn reduced investment and impeded economic activity. Furthermore, the consumption preference and the export mark-up shocks were another sources that contributed negatively to GDP growth, reflecting the increase in households' precautionary saving and the fall in exports, respectively. The slowdown in GDP growth was also accompanied by permanent (unit-root) technology shocks that could be considered as associated with the lack of productivity-enhancing and other structural reforms in the run-up to the crisis. By contrast, transitory (stationary) technology shocks have positively contributed to GDP growth during the crisis, especially in the second recessionary period, which may be interpreted as resulting from a temporary greater tendency of corporate sector to take restructuring measures in response to the crisis to enhance its technology and production efficiency. Finally, the results show that the recovery phase after 2013 is explained mainly by consumption preference shocks, which could be explained by the increased consumer confidence, resolution of banking system problems as well as by the improvement in the labour market situation.

The main purpose of the second chapter was to evaluate the macroeconomic effects of alternative types of fiscal rules. In particular, I limit my attention to five fiscal rules, namely the optimal simple rule, the balanced budget rule, the structural balance rule, the basic debt brake rule and the optimal debt brake rule. After having specified the rules, I aimed to address the following research questions: what is the volatility of real GDP growth, real government consumption growth, budget balance and public debt under different fiscal rules? Which fiscal rule delivers the smallest fiscal authority loss function defined as a weighted sum of inflation and output gap? How the selected macroeconomic variables in Slovenia would have evolved in the 1995-2014 period if the government had actually followed the aforementioned fiscal rules? In order to answer these questions, a DSGE model from the first chapter augmented with the fiscal block was used. The first finding is that all types of fiscal rules increase government expenditure stability and the welfare compared to of what it would be if a fiscal authority committed itself to the BBR. Specifically, I find that the OSR is the best welfare performer within the set I consider. The second best performance belongs to the OptDBR, while the third best performance occurs when the government follows the DBR. Concerning the public debt stabilization, the following results emerge: I find that the OSR and DBR give quite similar results regarding the public debt volatility. Further, comparing the public debt volatility under the DBR and OptDBR, one can note that while the latter is more successful in reducing the volatility of GDP growth movements, it gives higher volatility of public debt relative to the volatility implied by the DBR, indicating that there exists a trade-off between these two objectives. Finally, the lowest volatility of public debt is achieved under the BBR and SBR, where both rules generate quite comparable results. Lastly, the results based on historical counter-factual simulations show that Slovenia would have experienced more sustainable public debt path compared to the actual one, if a fiscal rule had been used since 1995. This would have several positive macroeconomic consequences, including decreasing interest rates, capital inflow, optimistic expectations, increase in economic activity and subsequent improvement in public finances.

In the third chapter, we developed a DSGE model with electricity, estimated and calibrated for the Slovenian economy. We illustrated the potential use of the model by presenting its dynamic properties throughout the discussion of results of some hypothetical scenarios involving price changes in the electricity price components. In this context, we concentrated our analysis on the price of energy. Further, we empirically evaluated the effects of electricity price changes on the Slovenian economy. In particular, we distinguished three different scenarios. In the first scenario, we assumed a 1 % permanent increase in the wholesale electricity prices. In the second scenario, we simulated the effects of a 1 % increase in the electricity prices for household and industrial consumers, respectively. And in the third scenario we looked at the effects of a 4 % permanent increase in the electricity prices, which occurs within a one-year horizon. Obviously, numerous other scenarios can be analysed within the model. Overall, we found our proposed model well suited for performing electricity sector related analyses within companies operating in the electricity sector.

Contributions, limitations and future research suggestions

This section presents contributions and briefly highlights some of the limitations and suggestions for future research.

The first chapter contributes to the knowledge in the following three ways: First, from the methodological point of view, it applies the Bayesian estimation method to the estimation of a medium-scale DSGE model for the Slovenian economy, and therefore, presents evidence for additional country on the estimates of the structural (deep) parameters. To the best of my knowledge, this is the first attempt to estimate a medium-scale DSGE model for Slovenia. Second, from the empirical point of view, this chapter contributes to the knowledge by identifying the shocks that were responsible for the recent recession and the key sources of macroeconomic fluctuations in Slovenia. Finally, giving a detailed description of DSGE modelling and illustrating the application of the model to the analysis of the business cycle fluctuations, the chapter also has important practical contributions for the Slovenian policy institutions, which may be interested in using the model presented here to support their policy processes.

The main limitation of the first chapter concerns the fact that the model I used ignores financial shocks which were arguably at the core of the last recession. There are at least three financial shocks that could be included in the model. The first financial shock could be related with the sudden loss of financing opportunities of Slovenian banks on international markets. It is well known that in the years before crisis Slovenia experienced excessive credit growth which was extensively based on foreign borrowing. When the recession hit the global economy, the inflow of cheap credit from abroad stopped, further increased banking lending rates and funding costs. The second financial shock could be due to inappropriate credit approval decisions made by Slovenian banks in the past, which further led to a large amount of non-performing bad loans that accumulated on banks' balance sheets which again raised lending rates and depressed credit activity. The third financial shock could be related to the sovereign debt crisis that followed. This in turn deteriorated Slovenia's creditworthiness position which also increased borrowing costs in the economy. Another possible limitation to consider is that when estimating the model, I did not account for the monetary regime change that occurred in 2007 when Slovenia adopted the euro. Lastly, one of the limitations of this chapter could also be related to DSGE modelling framework. The most problematic issues which are currently much discussed in the literature are mainly concerned with: (i) unrealistic assumptions (e.g. Ricardian equivalence, rational expectations hypothesis, infinitely-lived households, etc.), (ii) unconvincing method of estimation (which is a combination of calibration and Bayesian estimation), (iii) questionable assumption about the structural parameters that are assumed to be invariant to policy changes, (iv) issue related with the use of revised or real-time data when estimating the model and (v) poor performance during the recent crisis. All the issues outlined above are discussed in detail in Romer (2016) and Blanchard (2016) as well as in Blanchard (2017) which provides an extensive list of other useful references. Despite these shortcomings, I decided to use a DSGE framework as I believe that it is flexible enough to be used for the purposes of this dissertation, while other models are more limited in terms of their ability to fully address the research questions under study.

When preparing this chapter, I also identified two areas where the model could be extended. The first major area is the banking and financial system. In the current version of the model banking and financial system do not play particular role since investment is financed by households' savings without involvement of financial institutions. The modelling of the banking and financial systems and of their importance for economic developments is therefore obviously an area of future investigation. This would make the model useful in predicting future financial crisis as well as in studying macroprudential policies. These are also the topics which have already elicited considerable research effort in the recent crisis. The labour market is a second major area where the model could be improved. Currently the model assumes Calvo-type wage stickiness and involuntary unemployment. In the future it would be interesting to adapt the model with a detailed description of the labour market. In this regard, it would be sensible to introduce unemployment into the model structure by assuming search frictions and other labour market institutions in order to make the model structure more realistic.[62]

[62] See Mortensen, 1986; Boone & Bovenberg, 2002.

The analysis performed in the second chapter contributes to the literature on DSGE models for fiscal policy analysis in three ways: First, impulse responses properties of the five fiscal rules to a negative investment shock are explored. The motivation for considering this exercise is that the estimation results and historical decomposition analysis from the first chapter show that investment shocks accounted for a large share of output growth fluctuations in Slovenian economy during the last recessions. Second, I study the implications of the different fiscal rules for macroeconomic volatility and compare which of these rules is better from a welfare perspective. Last, I conduct a counter-factual historical analysis of the alternative fiscal rules, which consists of contrasting actual paths of selected macroeconomic variables in Slovenia during the 1995-2014 period with the values that would have been implied by each of the five fiscal rules. The limitations of this chapter point towards topics to be addressed in the future. Further research could concentrate on the various policy instruments (e.g. the tax rate on labour income, capital income and consumption) that could be adjusted to satisfy the fiscal rules. Furthermore, one could specify optimal simple fiscal rules for other policy instruments instead of focusing only on the government consumption. Another potential avenue of future research could be to investigate the interaction of fiscal and monetary policy, and how this would affect the overall results. In this context, one could search for the best combination of monetary and fiscal policy actions when the economy is hit by different shocks. It would also be interesting to extend the model to make government spending useful (instead of treating it as wasteful) either by allowing for households to enjoy utility directly from the consumption of public goods, or by letting government spending enhance productivity. In the future, fiscal variables could also be used to estimate the model. Future work could also use other approaches for fiscal rules evaluation. In the existing chapter, I employed a counter-factual and impulse responses analysis. The basic idea behind the latter approach is to apply shocks to the model and analyse how the economy responds in the presence of a rule. In addition to these two approaches, it would be of great interest to adapt the model to be suitable for conducting some sort of scenario analysis. For instance, one could simulate the effects of rules under various scenarios about the expected future path of the output gap (see, for example, IMF, 2009). I leave these extensions for future work.

Finally, the contribution to knowledge of the third chapter provides a methodological, empirical and practical contribution in the electricity-DSGE field. From a methodological point of view, this chapter develops an analytical framework based on a DSGE model that is suitable for carrying out electricity sector related analyses. This is to the best of our knowledge the first attempt to incorporate electricity in a DSGE model that reflects specific features of the Slovenian electricity market. Empirical contribution arises from the assessment of the effects of electricity price changes on the Slovenian economy. And lastly, practical contribution of this chapter is that it sets up the model that could be used for practical purposes inside companies operating in the electricity sector. Our study thus responds to the call made by one of these companies for the development and calibration of the model for Slovenia in order to enable company's staff to perform electricity sector related scenarios on their own after having received appropriate training. One of the limitations of the developed model is that electricity is the only energy source included in the model. As a consequence, it is possible that the results might slightly overestimate the impact on economic indicators since economic agents cannot substitute electricity with other energy sources. In terms of future work, it would also be interesting to include the electricity generating sector into the existing model. We leave these extensions for future maintenance and development of the model.

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APPENDICES

Appendix A. Steady state of the baseline model specification

The steady state of the model is computed as in Adolfson et al. (2007). In the following, I provide a brief summary. The stationary first-order condition for b_{t+1} in steady state reads as:

$$-1+\beta\left[\frac{1}{\mu_z}\frac{1}{\pi^d}\left(R-\tau^k\left(R-1\right)\right)\right]=0 \tag{A.1}$$

or equivalently:

$$\begin{aligned} R-\tau^k\left(R-1\right) &= \frac{\pi^d\mu_z}{\beta} \\ &\Leftrightarrow \\ R &= \frac{\pi\mu_z-\tau^k\beta}{\left(1-\tau^k\right)\beta}. \end{aligned} \tag{A.2}$$

The stationarized first-order condition for b^*_{t+1} can be simplified to:

$$-1+\beta\left[\frac{1}{\mu_z\pi^d}\left(R^*\Phi\left(\frac{A}{z},\tilde{\phi}\right)-\tau^k\left(R^*\Phi\left(\frac{A}{z},\tilde{\phi}\right)-1\right)\right)\right]=0. \tag{A.3}$$

Assuming that:

$$R^*=R, \tag{A.4}$$

then it can be seen by comparison of (A.1) and (A.3) that one possible steady state is characterized by:

$$\Phi\left(\frac{A_t}{z_t},\tilde{\phi}\right)=\Phi\left(\frac{A}{z},\tilde{\phi}\right)=1, \tag{A.5}$$

which with the assumption that $\Phi\left(\frac{A}{z},\tilde{\phi}\right)=\exp\left(-\tilde{\phi}_a A/z+\tilde{\phi}\right)$ implies that $B^*=A=0$, and $\tilde{\phi}=0$. Thus, in steady state, the net foreign asset position is zero. Using $F_1=1$, $F_2=0$ and $\Upsilon=1$, the first-order condition for i_t simplifies to:

$$P_{k'}=\frac{P^i}{P^d}. \tag{A.6}$$

To determine the relative prices in steady state the model assumes in addition to $R=R^*$ that $\pi=\pi^*$ and that $P_0=P_0^*$. The latter assumption means that the steady state price levels in the beginning of time were the same. The relative price between the CPI price index and domestically produced goods is given by:

$$\gamma_t^{c,d}\equiv\frac{P_t^c}{P_t^d}=\left[\left(1-\omega_c\right)+\omega_c\left(\frac{P_t^{m,c}}{P_t^d}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)}, \tag{A.7}$$

while the relative price between the CPI price index and imported consumption goods reads as:

$$\gamma_t^{c,mc}\equiv\frac{P_t^c}{P_t^{m,c}}=\left[\left(1-\omega_c\right)\left(\frac{P_t^d}{P_t^{m,c}}\right)^{1-\eta_c}+\omega_c\right]^{1/(1-\eta_c)}. \tag{A.8}$$

Combining (A.7) and (A.8) evaluated in steady state, yields:

$$\gamma^{c,d} = \left[(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \frac{P^*}{P^d} \right)^{1-\eta_c} \right]^{1/(1-\eta_c)} \tag{A.9}$$

and:

$$\gamma^{c,mc} = \left[(1-\omega_c) \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \frac{P^d}{P^*} \right)^{1-\eta_c} + \omega_c \right]^{1/(1-\eta_c)} , \tag{A.10}$$

where the notation $\frac{\eta^{m,c}}{\eta^{m,c}-1} = \lambda^{m,c}$ is used, i.e. $\eta^{m,c}$ is the substitution elasticity among the imported consumption goods. Under the above assumption, it holds that $\frac{P_t^*}{P_t^d} = 1$ and consequently:

$$\gamma^{c,d} = \left[(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right)^{1-\eta_c} \right]^{1/(1-\eta_c)} \tag{A.11}$$

and also:

$$\gamma^{c,mc} = \left[(1-\omega_c) \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right)^{1-\eta_c} + \omega_c \right]^{1/(1-\eta_c)} . \tag{A.12}$$

Similarly, the relative price between the aggregate investment and domestically produced goods is given by:

$$\gamma^{i,d} \equiv \frac{P^i}{P^d} = \left[(1-\omega_i) + \omega_i \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i} \right]^{1/(1-\eta_i)} , \tag{A.13}$$

while the relative price between the aggregate investment and imported investment goods reads as:

$$\gamma^{i,mi} \equiv \frac{P^i}{P^{m,i}} = \left[(1-\omega_i) \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i} + \omega_i \right]^{1/(1-\eta_i)} . \tag{A.14}$$

Combining equations (A.11) and (A.12), it follows that:

$$\frac{P^{m,c}}{P^d} = \left[\frac{(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right)^{1-\eta_c}}{(1-\omega_c) \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right)^{1-\eta_c} + \omega_c} \right]^{1/(1-\eta_c)} = \frac{\eta^{m,c}}{\eta^{m,c}-1}, \tag{A.15}$$

while equations (A.13) and (A.14) give:

$$\frac{P^{m,i}}{P^d} = \left[\frac{(1-\omega_i) + \omega_i \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i}}{(1-\omega_i) \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i} + \omega_i} \right]^{1/(1-\eta_i)} = \frac{\eta^{m,i}}{\eta^{m,i}-1}. \tag{A.16}$$

Furthermore, the model assumes that the export price equals the foreign price level in steady state, i.e. $P^x = P^*$, which implies that the steady state markup in the export market must be one:

$$P^x = P^d. \tag{A.17}$$

Using $P_{k'} = \frac{P^i}{P^d}$ and $u_t = \frac{k_t}{\bar{k}_t} = u = 1 \Rightarrow a(u) = a(1) = 0$ in the first-order condition for $\bar{k}_{t+1}$, it is possible to obtain:

$$\begin{aligned} \beta \left[\frac{1}{\mu_z} (1-\delta) P_{k'} + \left(1-\tau^k\right) \tau^k \right] &= P_{k'} \\ &\Leftrightarrow \\ r^k &= \frac{\mu_z P_{k'} - \beta (1-\delta) P_{k'}}{(1-\tau^k)\beta}. \end{aligned} \tag{A.18}$$

Using the scaled equilibrium rental rate of capital, it follows that:

$$r^k = \frac{\alpha}{1-\alpha} \mu_z \bar{w} \frac{H}{k}. \tag{A.19}$$

Using that:

$$P^d = \lambda^d MC^d \tag{A.20}$$

in steady state, or equivalently:

$$\frac{MC^d}{P^d} = \frac{1}{\lambda^d}, \tag{A.21}$$

it follows from the equilibrium real marginal cost:

$$\frac{1}{\lambda^d} = \left(\frac{1}{1-\alpha}\right)^{(1-\alpha)} \left(\frac{1}{\alpha}\right)^{\alpha} \left(r^k\right)^{\alpha} (\bar{w})^{(1-\alpha)}. \tag{A.22}$$

Real profit for domestic firm is given by:

$$\Pi^d \equiv \left(\frac{P^d}{MC^d}\right) y - r^k \frac{k}{\mu_z} - \bar{w} H - \phi. \tag{A.23}$$

Under perfect competition there is no markup (profits are zero), and y must equal $y = r^k \frac{k}{\mu_z} - \bar{w}H$. To impose $\Pi^d = 0$ in steady state also in monopolistic case, the size of the fixed cost, ϕ, needs to be determined such that this zero profit condition is fulfilled. The zero profit condition reduces to:

$$\Pi^d \equiv \lambda^d y - y - \phi = 0 \tag{A.24}$$

or equivalently:

$$\phi = \left(\lambda^d - 1\right) y. \tag{A.25}$$

Another way to write above condition is to use the steady-state version of production function:

$$\phi = \left(\lambda^d - 1\right) \left(\mu_z^{-\alpha} k^{\alpha} H^{(1-\alpha)} - \phi\right) \tag{A.26}$$

or equivalently:

$$\phi = \frac{\lambda^d - 1}{\lambda^d} \mu_z^{-\alpha} \left(\frac{k}{H}\right)^{\alpha} H. \tag{A.27}$$

From the law of motion for capital, it follows in steady state:

$$k = \frac{1-\delta}{\mu_z} k + i \tag{A.28}$$

or equivalently:

$$i = \left(1 - \frac{1-\delta}{\mu_z}\right) k. \tag{A.29}$$

The consumption Euler equation in steady state is given by:

$$\frac{1}{c - bc\frac{1}{\mu_z}} - \beta b \frac{1}{c\mu_z - bc} - \psi_z \frac{P^c}{P^d}\left(1+\tau^c\right) = 0 \tag{A.30}$$

or equivalently:

$$\psi_z = \frac{1}{c}\frac{\mu_z - \beta b}{\left(1+\tau^c\right)\left(\mu_z - b\right)}\left(\frac{P^c}{P^d}\right)^{-1}. \tag{A.31}$$

The first order condition for the households labour decision in steady state reads as:

$$-A_L H^{\sigma_L} + \left(1 - \tau^y + rr\right)\frac{\psi_z}{\lambda^w}\bar{w} = 0 \tag{A.32}$$

or equivalently:

$$H = \left[\frac{\left(1-\tau^y+rr\right)\frac{\psi_z}{\lambda^w}\bar{w}}{A_L}\right]^{1/\sigma_L}. \tag{A.33}$$

The resource constraint in steady-state is given by:

$$c^d + i^d + c^x + i^x = \left(1-g_r\right)\left(\mu_z^{-\alpha}\left(\frac{k}{H}\right)^{\alpha} H - \phi\right). \tag{A.34}$$

Using demand functions for domestic consumption goods and domestic investment goods, yields:

$$\left(1-\omega_c\right)\left[\frac{P^c}{P^d}\right]^{\eta_c} c + \left(1-\omega_i\right)\left[\frac{P^i}{P^d}\right]^{\eta_i} i + c^x + i^x = \frac{\left(1-g_r\right)}{\lambda^d}\mu_z^{-\alpha}\left(\frac{k}{H}\right)^{\alpha} H. \tag{A.35}$$

Furthermore, the model assumes that export equals import in steady-state which is consistent with a zero foreign debt in steady-state. From the equation that describes the evolution of net foreign assets at the aggregate level, it follows that:

$$c^m + i^m = c^x + i^x. \tag{A.36}$$

Using the demand functions for imported consumption goods and imported investment goods evaluated in steady state:

$$c^m = \omega_c\left[\frac{P^{m,c}}{P^c}\right]^{-\eta_c} c = \omega_c\left[\frac{P^c}{P^{m,c}}\right]^{\eta_c} c, \tag{A.37}$$

$$i^m = \omega_i\left[\frac{P^{m,i}}{P^i}\right]^{-\eta_i} i = \omega_i\left[\frac{P^i}{P^{m,i}}\right]^{\eta_i} i \tag{A.38}$$

the above condition can be rewritten as:

$$\begin{aligned}\omega_c\left[\frac{P^c}{P^{m,c}}\right]^{\eta_c} c + \omega_i\left[\frac{P^i}{P^{m,i}}\right]^{\eta_i} i &= c^x + i^x,\\ \omega_c\left[\frac{P^c}{P^{m,c}}\right]^{\eta_c} c + \omega_i\left[\frac{P^i}{P^{m,i}}\right]^{\eta_i} i &= \tilde{x},\end{aligned} \tag{A.39}$$

where $\tilde{x} \equiv c^x + i^x$. Inserting the steady state law of motion for capital into resource constraint, yields:

$$\begin{aligned}&\left((1-\omega_c)\left[\frac{P^c}{P^d}\right]^{\eta_c}+\omega_c\left[\frac{P^c}{P^{m,c}}\right]^{\eta_c}\right)c\\&+\left((1-\omega_i)\left[\frac{P^i}{P^d}\right]^{\eta_i}+\omega_i\left[\frac{P^i}{P^{m,i}}\right]^{\eta_i}\right)\left(1-\frac{1-\delta}{\mu_z}\right)\left(\frac{k}{H}\right)H\\&=\frac{(1-g_r)}{\lambda^d}\mu_z^{-\alpha}\left(\frac{k}{H}\right)^{\alpha}H\end{aligned} \tag{A.40}$$

or equivalently:

$$\begin{aligned}\left((1-\omega_c)\left[\frac{P^c}{P^d}\right]^{\eta_c}+\omega_c\left[\frac{P^c}{P^{m,c}}\right]^{\eta_c}\right)c=&\left[\frac{(1-g_r)}{\lambda^d}\mu_z^{-\alpha}\left(\frac{k}{H}\right)^{\alpha}\right.\\&\left.-\left((1-\omega_i)\left[\frac{P^i}{P^d}\right]^{\eta_i}+\omega_i\left[\frac{P^i}{P^{m,i}}\right]^{\eta_i}\right)\left(1-\frac{1-\delta}{\mu_z}\right)\left(\frac{k}{H}\right)\right]H.\end{aligned} \tag{A.41}$$

In order to calculate the steady-state values of H, c and ψ_z the following definitions have to be introduced:

$$D_1 \equiv (1-\omega_c)\left[\frac{P^c}{P^d}\right]^{\eta_c}+\omega_c\left[\frac{P^c}{P^{m,c}}\right]^{\eta_c} \tag{A.42}$$

$$\begin{aligned}D_2 \equiv &\left[\frac{(1-g_r)}{\lambda^d}\mu_z^{-\alpha}\left(\frac{k}{H}\right)^{\alpha}-\left((1-\omega_i)\left[\frac{P^i}{P^d}\right]^{\eta_i}+\omega_i\left[\frac{P^i}{P^{m,i}}\right]^{\eta_i}\right)\right.\\&\left.\left(1-\frac{1-\delta}{\mu_z}\right)\left(\frac{k}{H}\right)\right]\end{aligned} \tag{A.43}$$

$$D_3 \equiv \left[\frac{(1-\tau^y+rr)\frac{1}{\lambda^w}\bar{w}}{A_L}\right]^{1/\sigma_L} \tag{A.44}$$

$$D_4 \equiv \frac{\mu_z-\beta b}{(1+\tau^c)(\mu_z-b)}\left(\frac{P^c}{P^d}\right)^{-1}. \tag{A.45}$$

Then, the following system of equations can be derived:

$$D_1 c = D_2 H \tag{A.46}$$

$$H = D_3(\psi_z)^{1/\sigma_L} \tag{A.47}$$

$$\psi_z = \frac{1}{c}D_4 \tag{A.48}$$

and the solutions for H, c and ψ_z are given by:

$$H = \left[D_3 D_4^{1/\sigma_L}\left(\frac{D_2}{D_1}\right)^{-1/\sigma_L}\right]^{\frac{\sigma_L}{1+\sigma_L}} \tag{A.49}$$

$$c = \frac{D_2}{D_1}H \tag{A.50}$$

$$\psi_z = \frac{1}{c} D_4. \tag{A.51}$$

Once obtained the solution for H, one can compute y as:

$$y = \frac{1}{\lambda^d} \mu_z^{-\alpha} \left(\frac{k}{H} \right)^{\alpha} H \tag{A.52}$$

using the solution for $\frac{k}{H}$. ϕ is computed using (A.27) and steady state government consumption as:

$$g = g_r y. \tag{A.53}$$

The first-order condition for the capital utilization rate evaluated in steady state equals:

$$a'(1) = \left(1 - \tau^k\right) r^k. \tag{A.54}$$

Having derived the steady state relationships, one can compute $P_{k'}$, r^k, $\bar{w}$, R and $\frac{H}{k}$ in the following way: first, R can be computed from (A.2), second, r^k is obtained from (A.6) and (A.19), third $\bar{w}$ can be computed from (A.22), and fifth, the solutions for r^k and $\bar{w}$ can be used together with (A.19) to get $\frac{H}{k}$. Using these results, one can obtain c, i, y, g, ϕ, ψ_z, H, k, and $\tilde{x}$ in the following way. First, the composite coefficients D_1, D_2, D_3 and D_4 in (A.44) have to be defined. Second, (A.49) can be used to compute c, H and ψ_z. Third, (A.27) is used to compute ϕ. Forth, by multiplying $\frac{k}{H}$ with H, k is obtained. Fifth, (A.52) can be used to compute y. Sixth, g is computed from (A.53). Seventh, $A.29$ can be used to obtain i. Eighth, $A.39$ can be used to compute $\tilde{x}$.

Appendix B. Derivation of the wage-setting equation

This appendix contains a detailed derivation of the first order condition for the wage-setting equation.[63]

Labour demand function rewritten in stationarized form is given by:

$$\begin{aligned}
h_{j,t+s} &= \left(\frac{W_{j,t+s}}{W_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\
&= \left(\frac{W_{j,t+s}}{\frac{W_{t+s}}{z_{t+s} P_{t+s}} z_{t+s} P_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\
&= \left(\frac{W_{j,t+s}}{\frac{W_{t+s}}{z_{t+s} P_{t+s}} z_{t+s} P_t \pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\
&= \left(\frac{W_{j,t+s}}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\
&= \left(\frac{W_{j,t} \left(\pi_t^c \pi_{t+1}^c \ldots \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c \ldots \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} \ldots \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s}.
\end{aligned} \tag{B.1}$$

[63]Contrary to the paper of Adolfson et al. (2007), the model that I use additionally includes social transfers and unemployment benefits in the household's budget constraint. This requires me to vary the first order condition slightly. For this reason, I present here a full derivation of the wage-setting equation.

Each household j that is allowed to reoptimize, faces the following optimization problem:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta \xi_w)^s \left\{ -\zeta_{t+s}^h A_L \frac{(h_{j,t+s})^{1+\sigma_L}}{1+\sigma_L} + v_{t+s} \left(1 - \tau^y + rr_{t+s}\right) W_{j,t+s} h_{j,t+s} \right\}. \tag{B.2}$$

Substituting out for $h_{j,t+s}$ using the demand schedule, gives:

$$\max_{W_{j,t}^{opt}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h z \left[\left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +v_{t+s} \left(1-\tau^y\right) W_{j,t+s} \left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +v_{t+s} W_{j,t+s} rr_{t+s} \left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \end{array} \right\}. \tag{B.3}$$

Using $v_{t+s} = \frac{\psi_{t+s}}{P_{t+s}}$, gives:

$$\max_{W_{j,t}^{opt}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h z \left[\left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +\frac{\psi_{t+s}}{P_{t+s}} \left(1-\tau^y\right) W_{j,t+s} \left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\frac{\psi_{t+s}}{P_{t+s}} W_{j,t+s} rr_{t+s} \left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \end{array} \right\}. \tag{B.4}$$

Further, using the fact that:

$$\begin{aligned} W_{j,t+s} &= \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right) W_{j,t} \\ P_{t+s} &= P_t \pi_{t+1} \times \cdots \times \pi_{t+s} = P_t \frac{P_{t+1}}{P_t} \frac{P_{t+2}}{P_{t+1}} \frac{P_{t+3}}{P_{t+2}} \times \cdots \times \frac{P_{t+s-1}}{P_{t+s-2}} \frac{P_{t+s}}{P_{t+s-1}} = P_t \frac{P_{t+s}}{P_t} = P_{t+s} \\ \frac{W_{j,t+s}}{P_{t+s}} &= \frac{\left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right) W_{j,t}}{P_t \pi_{t+1} \times \cdots \times \pi_{t+s}}, \end{aligned} \tag{B.5}$$

one can obtain:

$$\max_{W_{j,t}^{opt}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h z \left[\left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +\psi_{t+s} \left(1-\tau^y\right) \frac{\left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right) W_{j,t}^{opt}}{P_t \pi_{t+1} \times \cdots \times \pi_{t+s}} \\ \times \left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{t+s} \frac{\left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right) W_{j,t}^{opt}}{P_t \pi_{t+1} \times \cdots \times \pi_{t+s}} \\ \times rr_{t+s} \left(\frac{W_{j,t}^{opt} \left(\pi_t^c \pi_{t+1}^c ... \pi_{t+s-1}^c\right)^{\kappa_w} \left(\bar{\pi}_{t+1}^c \bar{\pi}_{t+2}^c ... \bar{\pi}_{t+s}^c\right)^{1-\kappa_w} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} \frac{1}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \end{array} \right\}. \tag{B.6}$$

After rearranging, one can get:

$$\max_{W_{j,t}^{opt}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h z \left[\left(\frac{W_{j,t}^{opt} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +\psi_{t+s} \left(1-\tau^y\right) \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right) \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\frac{1}{z_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{t+s} \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right) \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\frac{1}{z_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \end{array} \right\} \tag{B.7}$$

or:

$$\max_{W_{j,t}^{opt}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h z \left[\left(\frac{W_{j,t}^{opt} \left(\mu_{z,t+1} ... \mu_{z,t+s}\right)}{w_{t+s} z_{t+s} P_t} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +z_{t+s} \psi_{t+s} \frac{1}{z_{t+s}} \left(\frac{1}{z_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(1-\tau^y\right) \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right) \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +z_{t+s} \psi_{t+s} \frac{1}{z_{t+s}} \left(\frac{1}{z_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right) \left(\frac{W_{j,t}^{opt} \mu_{z,t+1} \times \cdots \times \mu_{z,t+s}}{P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \end{array} \right\}. \tag{B.8}$$

After using that $\psi_{z,t+s} = z_{t+s}\psi_{t+s}$, it is possible to obtain:

$$\max_{W^{opt}_{j,t}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta^h_{t+s} z \left[\left(\frac{W^{opt}_{j,t}(\mu_{z,t+1}\cdots\mu_{z,t+s})}{w_{t+s} z_{t+s} P_t} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +\psi_{z,t+s} \left(\frac{1}{z_{t+s}} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} (1-\tau^y) \left(\frac{W^{opt}_{j,t}\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{P_t} \right) \left(\frac{W^{opt}_{j,t}\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{z,t+s} \left(\frac{1}{z_{t+s}} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} \left(\frac{W^{opt}_{j,t}\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{P_t} \right) \left(\frac{W^{opt}_{j,t}\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \end{array} \right\} \tag{B.9}$$

which can be further rewritten as follows:

$$\max_{W^{opt}_{j,t}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta^h_{t+s} z \left[\left(\frac{W^{opt}_{j,t}(\mu_{z,t+1}\cdots\mu_{z,t+s})}{w_{t+s} z_{t+s} P_t} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +\psi_{z,t+s} (1-\tau^y) \left(\frac{W^{opt}_{j,t}\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{z_{t+s} P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{z,t+s} \left(\frac{W^{opt}_{j,t}\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{z_{t+s} P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \end{array} \right\}. \tag{B.10}$$

Next, using the fact that:

$$\frac{\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{z_{t+s}} = \frac{\mu_{z,t+1}\times\cdots\times\mu_{z,t+s}}{\mu_{z,t+1}\times\cdots\times\mu_{z,t+s} z_t} = \frac{1}{z_t} \tag{B.11}$$

it follows:

$$\max_{W_{j,t}^{opt}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h z \left[\left(\frac{W_{j,t}^{opt}}{w_{t+s} z_t P_t} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \\ +\psi_{z,t+s} (1-\tau^y) \left(\frac{W_{j,t}^{opt}}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{z,t+s} \left(\frac{W_{j,t}^{opt}}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s}. \end{array} \right\}. \tag{B.12}$$

Differentiating above expression with respect to $W_{j,t}^{opt} = W_t^{opt}$, gives:

$$\begin{aligned} &\frac{\partial \left[\left(\frac{W_t^{opt}}{w_{t+s} z_t P_t} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right]}{\partial W_t^{opt}} \\ &= \frac{\lambda_w}{1-\lambda_w} \left(W_t^{opt} \right)^{\frac{\lambda_w}{1-\lambda_w}-1} \left(\frac{X_{t,s}}{w_{t+s} z_t P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \end{aligned} \tag{B.13}$$

$$\begin{aligned} &\frac{\partial \left[\psi_{z,t+s} \left(\frac{W_t^{opt}}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \right]}{\partial W_t^{opt}} \\ &= \psi_{z,t+s} \left(\frac{1}{1-\lambda_w} \right) \left(W_t^{opt} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\frac{1}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \end{aligned} \tag{B.14}$$

$$\begin{aligned} &\frac{\partial \left[\psi_{z,t+s} (1-\tau^y) \left(\frac{W_t^{opt}}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right]}{\partial W_t^{opt}} \\ &= \psi_{z,t+s} (1-\tau^y) \left(\frac{1}{1-\lambda_w} \right) \left(W_t^{opt} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\frac{1}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \end{aligned} \tag{B.15}$$

The first order condition reads as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta_{t+s}^h z' \left[\left(\frac{W_t^{opt}}{w_{t+s} z_t P_t} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \frac{\lambda_w}{1-\lambda_w} \left(W_t^{opt} \right)^{\frac{\lambda_w}{1-\lambda_w}-1} \left(\frac{X_{t,s}}{w_{t+s} z_t P_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{z,t+s} (1-\tau^y) \left(\frac{1}{1-\lambda_w} \right) \left(W_t^{opt} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\frac{1}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{z,t+s} \left(\frac{1}{1-\lambda_w} \right) \left(W_t^{opt} \right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\frac{1}{z_t P_t} \right)^{1+\frac{\lambda_w}{1-\lambda_w}} X_{t,s} \left(\frac{X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \end{array} \right\} = 0. \tag{B.16}$$

Multiplying above expression by $\dfrac{1-\lambda_w}{\lambda_w}\left(W_t^{opt}\right)^{-\frac{\lambda_w}{1-\lambda_w}+1}$, yields:

$$\mathbb{E}_t\sum_{s=0}^{\infty}(\beta\xi_w)^s\left\{\begin{array}{c} -\zeta_{t+s}^h z'\left[\left(\frac{W_t^{opt}}{w_{t+s}z_tP_t}X_{t,s}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}\right]\left(\frac{X_{t,s}}{w_{t+s}z_tP_t}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\left(1-\tau^y\right)\left(\frac{1}{\lambda_w}\right)W_t^{opt}\left(\frac{1}{z_tP_t}\right)^{1+\frac{\lambda_w}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\left(\frac{1}{\lambda_w}\right)W_t^{opt}\left(\frac{1}{z_tP_t}\right)^{1+\frac{\lambda_w}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}rr_{t+s} \end{array}\right\}=0. \tag{B.17}$$

Multiplying above expression by $P_t^{\frac{\lambda_w}{1-\lambda_w}}$, gives:

$$\mathbb{E}_t\sum_{s=0}^{\infty}(\beta\xi_w)^s\left\{\begin{array}{c} -\zeta_{t+s}^h z'\left[\left(\frac{W_t^{opt}}{w_{t+s}z_tP_t}X_{t,s}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}\right]\left(\frac{X_{t,s}}{w_{t+s}z_t}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\left(1-\tau^y\right)\frac{1}{\lambda_w}\frac{W_t^{opt}}{P_t}\left(\frac{1}{z_t}\right)^{\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\frac{1}{\lambda_w}\frac{W_t^{opt}}{P_t}\left(\frac{1}{z_t}\right)^{\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}rr_{t+s} \end{array}\right\}=0 \tag{B.18}$$

or:

$$\mathbb{E}_t\sum_{s=0}^{\infty}(\beta\xi_w)^s\left\{\begin{array}{c} -\zeta_{t+s}^h z'\left[\left(\frac{W_t^{opt}}{w_{t+s}z_tP_t}X_{t,s}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}\right]\left(\frac{X_{t,s}}{w_{t+s}z_t}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\left(1-\tau^y\right)\frac{1}{\lambda_w}\frac{W_t^{opt}}{P_t}\left(\frac{1}{z_t}\right)^{\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\frac{1}{\lambda_w}\frac{W_t^{opt}}{P_t}\left(\frac{1}{z_t}\right)^{\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}rr_{t+s} \end{array}\right\}=0. \tag{B.19}$$

Now, using $\tilde{w}_t=\frac{W_t^{opt}}{W_t}$ and $w_t=\frac{W_t}{z_tP_t}$, gives:

$$\mathbb{E}_t\sum_{s=0}^{\infty}(\beta\xi_w)^s\left\{\begin{array}{c} -\zeta_{t+s}^h z'\left[\left(\frac{\tilde{w}_tW_t}{w_{t+s}z_tP_t}X_{t,s}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}\right]\left(\frac{X_{t,s}}{w_{t+s}z_t}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\left(1-\tau^y\right)\frac{1}{\lambda_w}\frac{\tilde{w}_tW_t}{P_t}\left(\frac{1}{z_t}\right)^{\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\frac{1}{\lambda_w}\frac{\tilde{w}_tW_t}{P_t}\left(\frac{1}{z_t}\right)^{\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{w_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}rr_{t+s} \end{array}\right\}=0. \tag{B.20}$$

After some straightforward manipulations, this can be rewritten as:

$$\mathbb{E}_t\sum_{s=0}^{\infty}(\beta\xi_w)^s\left\{\begin{array}{c} -\zeta_{t+s}^h z'\left[\left(\frac{\tilde{w}_tz_tw_t}{w_{t+s}z_t}X_{t,s}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}\right]\left(\frac{X_{t,s}}{w_{t+s}z_t}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\left(1-\tau^y\right)\frac{1}{\lambda_w}\tilde{w}_tz_tw_tz_t^{\frac{\lambda_w}{1-\lambda_w}-\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{z_tw_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\frac{1}{\lambda_w}\tilde{w}_tz_tw_tz_t^{\frac{\lambda_w}{1-\lambda_w}-\frac{1}{1-\lambda_w}}X_{t,s}\left(\frac{X_{t,s}}{z_tw_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}rr_{t+s} \end{array}\right\}=0. \tag{B.21}$$

Now, using the fact that $z_t^{\frac{\lambda_w}{1-\lambda_w}-\frac{1}{1-\lambda_w}}=\frac{1}{z_t}$, gives:

$$\mathbb{E}_t\sum_{s=0}^{\infty}(\beta\xi_w)^s\left\{\begin{array}{c} -\zeta_{t+s}^h z'\left[\left(\frac{\tilde{w}_tw_t}{w_{t+s}}X_{t,s}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}\right]\left(\frac{X_{t,s}}{w_{t+s}z_t}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\left(1-\tau^y\right)\frac{1}{\lambda_w}\tilde{w}_tw_tX_{t,s}\left(\frac{X_{t,s}}{z_tw_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s} \\ +\psi_{z,t+s}\frac{1}{\lambda_w}\tilde{w}_tw_tX_{t,s}\left(\frac{X_{t,s}}{z_tw_{t+s}}\right)^{\frac{\lambda_w}{1-\lambda_w}}H_{t+s}rr_{t+s} \end{array}\right\}=0. \tag{B.22}$$

Multiplying both sides of this equation by $(\tilde{w}_t w_t z_t)^{\frac{\lambda_w}{1-\lambda_w}}$, yields:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} -\zeta^h_{t+s} z' \left[\left(\frac{\tilde{w}_t w_t}{w_{t+s}} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] \left(\frac{\tilde{w}_t w_t X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{z,t+s} (1-\tau^y) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,s} \left(\frac{\tilde{w}_t w_t X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ +\psi_{z,t+s} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,s} \left(\frac{\tilde{w}_t w_t X_{t,s}}{w_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} rr_{t+s} \end{array} \right\} = 0. \tag{B.23}$$

It is also known that:

$$\begin{aligned} h_{j,t+s} &= \left(\frac{\tilde{w}_t w_t}{w_{t+s}} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \\ &= \left(\frac{W_{j,t+s}}{W_{t+s}} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s}. \end{aligned} \tag{B.24}$$

So, this gives:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} \zeta^h_{t+s} f_L (h_{j,t+s}) h_{j,t+s} \\ +\psi_{z,t+s} (1-\tau^y) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,s} h_{j,t+s} \\ +\psi_{z,t+s} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,s} h_{j,t+s} rr_{t+s} \end{array} \right\} = 0. \tag{B.25}$$

where $f_L(h_{j,t+s}) = -z'_{t+s} = -A_L h^{\sigma_L}_{j,t+s}$, $\tilde{w}_t = \frac{W^{opt}_t}{W_t}$ and $w_t = \frac{W_t}{z_t P_t}$. It also holds that:

$$\begin{aligned} X_{t,s} &= \frac{\left(\pi^c_t \times \cdots \times \pi^c_{t+s-1}\right)^{\kappa_w} \left(\bar{\pi}^c_{t+1} \times \cdots \times \bar{\pi}^c_{t+s}\right)^{1-\kappa_w}}{\pi_{t+1} \times \cdots \times \pi_{t+s}} \\ &= \frac{\left(\frac{P^c_{t+s-1}}{P^c_{t-1}} \right)^{\kappa_w} \left(\bar{\pi}^c_{t+1} \times \cdots \times \bar{\pi}^c_{t+s}\right)^{1-\kappa_w}}{\frac{P_{t+s}}{P_t}}. \end{aligned} \tag{B.26}$$

Finally, the first order condition can be written as:

$$\begin{aligned} 0 =& \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left\{ \begin{array}{c} \zeta^h_{t+s} f_L \left[\left(\frac{\tilde{w}_t w_t}{w_{t+s}} X_{t,s} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+s} \right] h_{j,t+s} \\ +\psi_{z,t+s} (1-\tau^y) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,s} h_{j,t+s} \\ +\psi_{z,t+s} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,s} h_{j,t+s} rr_{t+s} \end{array} \right\} \\ =& \left\{ \begin{array}{c} \zeta^h_t f_L \left[(\tilde{w}_t X_{t,0})^{\frac{\lambda_w}{1-\lambda_w}} H_t \right] h_{j,t} \\ +\psi_{z,t} (1-\tau^y) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,0} h_{j,t} \\ +\psi_{z,t} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,0} h_{j,t} rr_t \end{array} \right\} \\ &+ (\beta\xi_w)^1 \left\{ \begin{array}{c} \zeta^h_{t+1} f_L \left[\left(\frac{\tilde{w}_t w_t}{w_{t+1}} X_{t,1} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+1} \right] h_{j,t+1} \\ +\psi_{z,t+1} (1-\tau^y) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,1} h_{j,t+1} \\ +\psi_{z,t+1} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,1} h_{j,t+1} rr_{t+1} \end{array} \right\} \\ &+ (\beta\xi_w)^2 \left\{ \begin{array}{c} \zeta^h_{t+2} f_L \left[\left(\frac{\tilde{w}_t w_t}{w_{t+2}} X_{t,2} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+2} \right] h_{j,t+2} \\ +\psi_{z,t+2} (1-\tau^y) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,2} h_{j,t+2} \\ +\psi_{z,t+2} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,2} h_{j,t+2} rr_{t+2} \end{array} \right\} \\ &+ (\beta\xi_w)^3 \left\{ \begin{array}{c} \zeta^h_{t+3} f_L \left[\left(\frac{\tilde{w}_t w_t}{w_{t+3}} X_{t,3} \right)^{\frac{\lambda_w}{1-\lambda_w}} H_{t+3} \right] h_{j,t+3} \\ +\psi_{z,t+3} (1-\tau^y) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,3} h_{j,t+3} \\ +\psi_{z,t+3} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,3} h_{j,t+3} rr_{t+3} \end{array} \right\} \\ &+ \ldots = 0. \end{aligned} \tag{B.27}$$

When $\xi_w = 0$, the above expression reduces to:

$$\begin{aligned} \zeta_t^h f_L \left[(\tilde{w}_t X_{t,0})^{\frac{\lambda_w}{1-\lambda_w}} H_t \right] h_{j,t} + \psi_{z,t} \left(1 - \tau^y\right) \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,0} h_{j,t} \\ + \psi_{z,t} \frac{1}{\lambda_w} \tilde{w}_t w_t X_{t,0} h_{j,t} rr_t = 0. \end{aligned} \tag{B.28}$$

Appendix C. Fiscal block of the model

The fiscal block of the model is characterized by the following set of equations.

Debt-to-GDP ratio

Debt-to-GDP ratio is defined as follows:

$$B_{y,t} = \frac{B_{t+1}}{P_t^d Y_t} \tag{C.1}$$

Stationarizing this, yields:

$$b_{y,t} = \frac{B_{t+1} z_t}{P_t^d z_t \frac{Y_t z_t}{z_t}} \tag{C.2}$$

Applying the Taylor approximation to the previous equation:

$$\hat{b}_{y,t} = \hat{b}_t - \hat{y}_t. \tag{C.3}$$

Deficit-to-GDP ratio

$$\widetilde{def}_{y,t} = \frac{\widetilde{def}_t}{y} - \frac{def}{y} \hat{y}_t. \tag{C.4}$$

Social security benefits

$$\widehat{ben}_t = \hat{\tau}_t^b + \hat{\tilde{w}}_t + \hat{H}_t. \tag{C.5}$$

Government expenditures

Government expenditures are defined as follows:

$$GEX_t = BEN_t + P_t^d G_t + (R_{t-1} - 1) B_t \tag{C.6}$$

Stationarizing this, yields:

$$\frac{GEX_t P_t^d z_t}{P_t^d z_t} = \frac{BEN_t P_t^d z_t}{P_t^d z_t} + \frac{P_t^d G_t P_t^d z_t}{P_t^d z_t} + (R_{t-1} - 1) \frac{B_t P_{t-1}^d z_{t-1}}{P_{t-1}^d z_{t-1}} \tag{C.7}$$

$$gex_t = ben_t + g_t + (R_{t-1} - 1) \frac{b_{t-1}}{\pi_t \mu_{z,t}}. \tag{C.8}$$

Applying the Taylor approximation to the previous equation:

$$\begin{aligned} gex\left(1+\widehat{gex}_t\right) =& ben\left(1+\widehat{ben}_t\right)+g\left(1+\widehat{g}_t\right)+\frac{Rb}{\pi\mu_z}\left(1+\hat{R}_{t-1}+\hat{b}_{t-1}-\hat{\pi}_t-\hat{\mu}_{z,t}\right) \\ & -\frac{b}{\pi\mu_z}\left(1+\hat{b}_{t-1}-\hat{\pi}_t-\hat{\mu}_{z,t}\right) \end{aligned} \tag{C.9}$$

$$\begin{aligned} \widehat{gex}_t =& \frac{ben}{gex}\widehat{ben}_t+\frac{g}{gex}\hat{g}_t+\frac{Rb}{\pi\mu_z gex}\hat{R}_{t-1}+\frac{Rb}{\pi\mu_z gex}\hat{b}_{t-1}-\frac{Rb}{\pi\mu_z gex}\hat{\pi}_t-\frac{Rb}{\pi\mu_z gex}\hat{\mu}_{z,t} \\ & -\frac{b}{\pi\mu_z gex}\hat{b}_{t-1}+\frac{b}{\pi\mu_z gex}\hat{\pi}_t+\frac{b}{\pi\mu_z gex}\hat{\mu}_{z,t} \end{aligned} \tag{C.10}$$

$$\begin{aligned} \widehat{gex}_t =& \frac{ben}{gex}\widehat{ben}_t+\frac{g}{gex}\hat{g}_t+\frac{Rb\left(R-1\right)}{\pi\mu_z gex\left(R-1\right)}\hat{R}_{t-1}+\frac{\left(R-1\right)b}{\pi\mu_z gex}\hat{b}_{t-1} \\ & -\frac{\left(R-1\right)b}{\pi\mu_z gex}\hat{\pi}_t-\frac{\left(R-1\right)b}{\pi\mu_z gex}\hat{\mu}_{z,t}. \end{aligned} \tag{C.11}$$

$$\widehat{gex}_t = \frac{ben}{gex}\widehat{ben}_t+\frac{g}{gex}\hat{g}_t+\frac{r}{gex}\frac{R}{\pi\mu_z\left(R-1\right)}\hat{R}_{t-1}+\frac{r}{gex}\frac{\hat{b}_{t-1}}{\pi\mu_z}-\frac{r}{gex}\frac{\hat{\pi}_t}{\pi\mu_z}-\frac{r}{gex}\frac{\hat{\mu}_{z,t}}{\pi\mu_z}. \tag{C.12}$$

Government budget constraint

The government budget constraint is defined as follows:

$$B_{t+1}+T_t = R_{t-1}B_t + BEN_t + P_t^d G_t. \tag{C.13}$$

Expressing in real terms and stationarizing, gives:

$$\frac{B_{t+1}}{P_t^d z_t}+\frac{T_t}{P_t^d z_t} = R_{t-1}\frac{B_t}{P_{t-1}^d z_{t-1}}+\frac{BEN_t}{P_t^d z_t}+\frac{P_t^d G_t}{P_t^d z_t} \tag{C.14}$$

or written differently:

$$b_t+t_t = R_{t-1}b_{t-1}\frac{P_{t-1}^d z_{t-1}}{P_t^d z_t}+ben_t+g_t. \tag{C.15}$$

Applying the Taylor approximation to the previous equation, yields:

$$b\hat{b}_t+t\hat{t}_t = \frac{Rb}{\pi^d\mu_z}\left(\hat{R}_{t-1}+\hat{b}_{t-1}-\hat{\pi}_t^d-\hat{\mu}_{z,t}\right)+ben\widehat{ben}_t+g\hat{g}_t. \tag{C.16}$$

Deficit

$$\widetilde{def}_t = gex\widehat{gex}_t - t\hat{t}_t. \tag{C.17}$$

Tax on consumption

The tax base for consumption tax is defined as follows:

$$T_t^a = P_t^c C_t. \tag{C.18}$$

Expressing in real terms and stationarizing, yields:

$$\frac{T_t^a}{P_t^d z_t} = \frac{P_t^c C_t}{P_t^d z_t} \tag{C.19}$$

or

$$t_t^a = \gamma_t^{c,d} c_t. \tag{C.20}$$

Applying the Taylor approximation to the previous equation, gives:

$$t^a \left(1 + \hat{t}_t^a\right) = \gamma^{c,d} c \left(1 + \hat{\gamma}_t^{c,d} + \hat{c}_t\right). \tag{C.21}$$

Since $t^a = \gamma^{c,d} c$ in the steady state, it holds that:

$$\hat{t}_t^a = \hat{\gamma}_t^{c,d} + \hat{c}_t \tag{C.22}$$

or:

$$\hat{t}_t^a = \omega_c \left(\gamma^{c,mc}\right)^{-(1-\eta_c)} \hat{\gamma}_t^{mc,d} + \hat{c}_t. \tag{C.23}$$

Taxes and contributions on wages

The tax base for income tax is defined as follows:

$$T_t^b = W_t H_t. \tag{C.24}$$

Expressing in real terms and stationarizing, gives:

$$\frac{T_t^b}{P_t^d z_t} = \frac{W_t H_t}{P_t^d z_t} \tag{C.25}$$

or:

$$t_t^b = \bar{w}_t H_t. \tag{C.26}$$

Applying the Taylor approximation to the previous equation, gives:

$$t^b \left(1 + \hat{t}_t^b\right) = \bar{w}_t H \left(1 + \hat{\bar{w}}_t + \hat{H}_t\right) \tag{C.27}$$

or:

$$\hat{t}_t^b = \hat{\bar{w}}_t + \hat{H}_t. \tag{C.28}$$

Public debt interest payments

The tax base for capital tax (public debt interest payments) is defined as follows:

$$T_t^c = \left(R_{t-1} - 1\right) B_t. \tag{C.29}$$

Expressing in real terms and stationarizing, gives:

$$\frac{T_t^c}{P_t^d z_t} = \frac{\left(R_{t-1} - 1\right) B_t P_{t-1}^d z_{t-1}}{P_{t-1}^d z_{t-1} P_t^d z_t} \tag{C.30}$$

or:

$$t_t^c = \left(R_{t-1} - 1\right) \frac{b_{t-1}}{\pi_t \mu_{z,t}}. \tag{C.31}$$

Applying the Taylor approximation to the previous equation, yields:

$$t^c \left(1 + \hat{t}_t^c\right) = R \frac{b}{\pi \mu_z} \left(1 + \hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t - \hat{\mu}_{z,t}\right) - \frac{b}{\pi \mu_z} \left(1 + \widehat{b}_{t-1} - \hat{\pi}_t - \hat{\mu}_{z,t}\right) \tag{C.32}$$

or:

$$\tilde{t}_t^c = \frac{Rb}{\pi \mu_z} \hat{R}_{t-1} + \frac{Rb}{\pi \mu_z} \hat{b}_{t-1} - \frac{Rb}{\pi \mu_z} \hat{\pi}_t - \frac{Rb}{\pi \mu_z} \hat{\mu}_{z,t} - \frac{b}{\pi \mu_z} \hat{b}_{t-1} + \frac{b}{\pi \mu_z} \hat{\pi}_t + \frac{b}{\pi \mu_z} \hat{\mu}_{z,t}. \tag{C.33}$$

Simplifying above expression and collecting like terms, gives:

$$\tilde{t}_t^c = \frac{Rb}{\pi \mu_z} \hat{R}_{t-1} + \frac{\left(R - 1\right) b}{\pi \mu_z} \hat{b}_{t-1} - \frac{\left(R - 1\right) b}{\pi \mu_z} \hat{\pi}_t - \frac{\left(R - 1\right) b}{\pi \mu_z} .\hat{\mu}_{z,t} \tag{C.34}$$

Interest on the amount of the capital services

The tax base for capital tax (interest on the amount of capital services) is defined as follows:

$$T_t^d = R_t^k K_t. \tag{C.35}$$

Expressing in real terms and stationarizing, gives:

$$\frac{T_t^d}{P_t^d z_t} = \frac{R_t^k K_t z_{t-1}}{P_t^d z_t z_{t-1}} \tag{C.36}$$

or:

$$t_t^d = \frac{r_t^k k_t}{\mu_{z,t}}. \tag{C.37}$$

Applying the Taylor approximation to the previous equation, gives:

$$t^d \left(1 + \hat{t}_t^d\right) = \frac{r^k k}{\mu_z} \left(1 + \hat{r}_t^k + \hat{k}_t - \hat{\mu}_{z,t}\right) \tag{C.38}$$

or:

$$\tilde{t}_t^d = \frac{r^k k}{\mu_z} \left(\hat{r}_t^k + \hat{k}_t - \hat{\mu}_{z,t}\right). \tag{C.39}$$

Interest on the amount of foreign bond holdings

The tax base for capital tax (interest on the amount of foreign bond holdings) is defined as follows:

$$T_t^e = \left(R_{t-1}^* \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right) - 1\right) B_t^*. \tag{C.40}$$

Expressing in real terms and stationarizing, it is possible to obtain:

$$\frac{T_t^e}{P_t^d z_t} = \left(R_{t-1}^* \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right) - 1\right) \frac{B_t^* P_{t-1}^d z_{t-1}}{P_{t-1}^d z_{t-1} P_t^d z_t} \tag{C.41}$$

or:

$$t_t^e = \left(R_{t-1}^* \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right) - 1\right) \frac{a_{t-1}}{\pi_t \mu_{z,t}}. \tag{C.42}$$

Applying the Taylor approximation to the previous equation, yields:

$$t_t^e = R_{t-1}^* \Phi\left(a_{t-1}, \tilde{\phi}_{t-1}\right) \frac{a_{t-1}}{\pi_t \mu_{z,t}} - \frac{a_{t-1}}{\pi_t \mu_{z,t}} \tag{C.43}$$

or:

$$\begin{aligned} t^e \hat{t}_t^e = & \left[\frac{R}{\pi \mu_z}\left(\Phi_a'(0,0)\, a + \Phi(0,0)\right) - \frac{1}{\pi \mu_z}\right] a \hat{a}_{t-1} + \frac{R \Phi(0,0)\, a}{\pi \mu_z} \hat{R}_{t-1}^* \\ & - \left(\frac{Ra}{\pi \mu_z} - \frac{a}{\pi \mu_z}\right)\left(\hat{\pi}_t + \hat{\mu}_{z,t}\right), \end{aligned} \tag{C.44}$$

which can be further simplified to:

$$\tilde{t}_t^e = \frac{R-1}{\pi \mu_z} \tilde{a}_{t-1}, \tag{C.45}$$

since $a = 0$ and $\Phi(0,0) = 1$.

Profit of domestic firms

The profit of domestic firms is defined as follows:

$$\Pi_t^d = P_t^d Y_t - MC_t^d Y_t - MC_t^d z_t \phi. \tag{C.46}$$

Stationarizing above expression, gives:

$$\frac{\Pi_t^d}{P_t^d z_t} = \frac{P_t^d Y_t}{P_t^d z_t} - \frac{MC_t^d Y_t}{P_t^d z_t} - \frac{MC_t^d z_t \phi^d}{P_t^d z_t}, \tag{C.47}$$

which can be further rewritten as:

$$\overline{\Pi}_t^d = y_t - mc_t^d y_t - mc_t^d \phi_t^d, \tag{C.48}$$

where one can use the following definitions: $\overline{\Pi}_t^d = \frac{\Pi_t^d}{P_t^d z_t}$, $y_t = \frac{Y_t}{P_t^d}$ and $mc_t^d = \frac{MC_t^d}{P_t^d}$. Differentiating this with respect to y_t and mc_t, gives:

$$\frac{\partial \overline{\Pi}_t^d}{\partial y_t} = \left(1 - mc^d\right) \tag{C.49}$$

$$\frac{\partial \overline{\Pi}_t^d}{\partial mc_t^d} = -\left(y + \phi^d\right). \tag{C.50}$$

Applying the Taylor approximation to the previous equation, yields:

$$\begin{aligned}\overline{\Pi}_t^d &= y\left(1 - mc^d\right)\hat{y}_t - mc\left(y + \phi^d\right)\widehat{mc}_t^d \\ &= y\left(\frac{\lambda^d - 1}{\lambda^d}\right)\hat{y}_t - \frac{1}{\lambda^d}\left(y + \phi^d\right)\widehat{mc}_t^d.\end{aligned} \tag{C.51}$$

Using this expression together with the expression for the real marginal cost, gives:

$$\tilde{\overline{\Pi}}_t^d = y\left(\frac{\lambda^d - 1}{\lambda^d}\right)\hat{y}_t - \frac{1}{\lambda^d}\left(y + \phi\right)\left[\alpha\left(\hat{\mu}_{z,t} + \hat{H}_t - \hat{k}_t\right) + \hat{\bar{w}}_t + \hat{R}_t^f - \hat{\epsilon}_t\right]. \tag{C.52}$$

Profit of importing firms

Total profits for the consumption and investment importing firms are given by:

$$\begin{aligned}\Pi_t^m &= \Pi_t^{m,c} + \Pi_t^{m,i} \\ &= P_t^{m,c}C_t^m + P_t^{m,i}I_t^m - P_t^*\left(C_t^m + I_t^m\right).\end{aligned} \tag{C.53}$$

Stationarizing above expression, yields:

$$\frac{\Pi_t^m}{P_t^d z_t} = \frac{P_t^{m,c}C_t^m}{P_t^d z_t} + \frac{P_t^{m,i}I_t^m}{P_t^d z_t} - \frac{P_t^*\left(C_t^m + I_t^m\right)}{P_t^d z_t} \tag{C.54}$$

or:

$$\begin{aligned}\overline{\Pi}_t^m &= \gamma_t^{mc,d}c_t^m + \gamma_t^{mi,d}i_t^m - \gamma_t^x\left(c_t^m + i_t^m\right) \\ &= \left(\gamma_t^{mc,d} - \gamma_t^x\right)c_t^m + \left(\gamma_t^{mi,d} - \gamma_t^x\right)i_t^m,\end{aligned} \tag{C.55}$$

where $\overline{\Pi}_t^m = \frac{\Pi_t^m}{P_t^d z_t}$, $\gamma_t^{mc,d} = \frac{P_t^{m,c}}{P_t^d}$, $\gamma_t^{mi,d} = \frac{P_t^{m,i}}{P_t^d}$ and $\gamma_t^x = \frac{P_t^*}{P_t^d}$. Differentiating this expression with respect to the variables c_t^m, i_t^m, $\gamma_t^{mc,d}$, $\gamma_t^{mi,d}$, γ_t^x and evaluating in steady state, gives:

$$\frac{\partial \overline{\Pi}_t^m}{\partial c_t^m} = \left(\gamma^{mc,d} - \gamma^x\right), \tag{C.56}$$

$$\frac{\partial \overline{\Pi}_t^m}{\partial i_t^m} = \left(\gamma^{mi,d} - \gamma^x\right), \tag{C.57}$$

$$\frac{\partial \overline{\Pi}_t^m}{\partial \gamma_t^{mc,d}} = c^m, \tag{C.58}$$

$$\frac{\partial \overline{\Pi}_t^m}{\partial \gamma_t^{mi,d}} = i^m, \tag{C.59}$$

and:

$$\frac{\partial \overline{\Pi}_t^m}{\partial \gamma_t^x} = -\left(c^m + i^m\right). \tag{C.60}$$

The Taylor expansion follows:

$$\begin{aligned}\widetilde{\overline{\Pi}}_t^m &= c^m \left(\gamma^{mc,d} - \gamma^x\right) \hat{c}_t^m + i^m \left(\gamma^{mi,d} - \gamma^x\right) \hat{i}_t^m + \gamma^{mc,d} c^m \hat{\gamma}_t^{mc,d} \\ &+ \gamma^{mi,d} i^m \hat{\gamma}_t^{mi,d} - \gamma^x \left(c^m + i^m\right) \hat{\gamma}_t^x.\end{aligned} \tag{C.61}$$

Imposing that the real profits for the importing consumption firm are zero in steady state, implies:

$$\overline{\Pi}^{m,c} = \frac{P^{m,c}}{P^d} c^m - \frac{P^*}{P^d} c^m - \phi^{m,c} = 0. \tag{C.62}$$

Using the steady state value of $P^{m,c} = \frac{\eta^{m,c}}{\eta^{m,c}-1} P^*$, and taking into account that $\frac{P^*}{P^d} = 1$, yields that the value of $\phi^{m,c}$ must equal:

$$\phi^{m,c} = \left(\frac{\eta^{m,c}}{\eta^{m,c} - 1} - 1\right) c^m. \tag{C.63}$$

Using this, gives:

$$\begin{aligned}\widetilde{\overline{\Pi}}_t^{m,c} =& \frac{P^{m,c}}{P^d} c^m - \frac{P^*}{P^d} c^m - \left(\frac{\eta^{m,c}}{\eta^{m,c} - 1} - 1\right) c^m \\ =& \frac{\left(\frac{\eta^{m,c}}{\eta^{m,c}-1} P^*\right)}{P^d} c^m - c^m - \left(\frac{\eta^{m,c}}{\eta^{m,c} - 1} - 1\right) c^m \\ =& \left(\frac{\eta^{m,c}}{\eta^{m,c} - 1} - 1\right) c^m - \left(\frac{\eta^{m,c}}{\eta^{m,c} - 1} - 1\right) c^m \\ =& 0.\end{aligned} \tag{C.64}$$

Equivalently holds for the importing investment firms:

$$\phi^{m,i} = \left(\frac{\eta^{m,i}}{\eta^{m,i} - 1} - 1\right) i^m. \tag{C.65}$$

The linearized profits must be:

$$\begin{aligned}\overline{\Pi}_t^m =& \gamma_t^{mc,d} c_t^m + \gamma_t^{mi,d} i_t^m - \gamma_t^x \left(c_t^m + i_t^m\right) - \gamma_t^x \left(\phi^{m,c} + \phi^{m,i}\right) \\ =& \left(\gamma_t^{mc,d} - \gamma_t^x\right) c_t^m + \left(\gamma_t^{mi,d} - \gamma_t^x\right) i_t^m - \gamma_t^x \left(\phi^{m,c} + \phi^{m,i}\right).\end{aligned} \tag{C.66}$$

Applying the Taylor approximation to the previous equation:

$$\begin{aligned}\widetilde{\overline{\Pi}}_t^m =& c^m \left(\gamma^{mc,d} - \gamma^x\right) \hat{c}_t^m + i^m \left(\gamma^{mi,d} - \gamma^x\right) \hat{i}_t^m + \gamma^{mc,d} c^m \hat{\gamma}_t^{mc,d} \\ &+ \gamma^{mi,d} i^m \hat{\gamma}_t^{mi,d} - \gamma^x \left(c^m + i^m + \phi^{m,c} + \phi^{m,i}\right) \hat{\gamma}_t^x \\ =& c^m \left(\gamma^{mc,d} - \gamma^x\right) \hat{c}_t^m + i^m \left(\gamma^{mi,d} - \gamma^x\right) \hat{i}_t^m + \gamma^{mc,d} c^m \hat{\gamma}_t^{mc,d} \\ &+ \gamma^{mi,d} i^m \hat{\gamma}_t^{mi,d} - \gamma^x \left[\left(\frac{\eta^{m,c}}{\eta^{m,c} - 1}\right) c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i} - 1}\right) i^m\right] \hat{\gamma}_t^x.\end{aligned} \tag{C.67}$$

Further, taking into account that $\gamma^x = \frac{1}{\gamma^f}$ and $\hat{\gamma}_t^x = -\hat{\gamma}_t^f$, and using the definitions of $\hat{c}_t^m$ and $\hat{i}_t^m$, one can obtain:

$$
\begin{aligned}
\overline{\widetilde{\Pi}}_t^m =& c^m\left(\gamma^{mc,d}-\frac{1}{\gamma^f}\right)\hat{c}_t^m + i^m\left(\gamma^{mi,d}-\frac{1}{\gamma^f}\right)\hat{i}_t^m + \gamma^{mc,d}c^m\hat{\gamma}_t^{mc,d} \\
&+\gamma^{mi,d}i^m\hat{\gamma}_t^{mi,d} - \frac{1}{\gamma^f}\left(c^m + i^m + \phi^{m,c} + \phi^{m,i}\right)\hat{\gamma}_t^f \\
=& c^m\left(\gamma^{mc,d}-\frac{1}{\gamma^f}\right)\hat{c}_t^m + i^m\left(\gamma^{mi,d}-\frac{1}{\gamma^f}\right)\hat{i}_t^m + \gamma^{mc,d}c^m\hat{\gamma}_t^{mc,d} \\
&+\gamma^{mi,d}i^m\hat{\gamma}_t^{mi,d} - \frac{1}{\gamma^f}\left[\left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i}-1}\right)i^m\right]\hat{\gamma}_t^f,
\end{aligned}
\tag{C.68}
$$

which can be further rewritten as:

$$
\begin{aligned}
\overline{\widetilde{\Pi}}_t^m =& \left\{c^m\left(\gamma^{mc,d}-\frac{1}{\lambda^d}\right)\eta_c\left[-(1-\omega_c)\left(\frac{1}{\gamma^{c,mc}\gamma^{mc,d}}\right)^{1-\eta_c}\right] + \gamma^{mc,d}c^m\right\}\hat{\gamma}_t^{mc,d} \\
&+c^m\left(\gamma^{mc,d}-\frac{1}{\lambda^d}\right)\hat{c}_t \\
&+\left\{i^m\left(\gamma^{mi,d}-\frac{1}{\lambda^d}\right)\eta_i\left[-(1-\omega_i)\left(\frac{1}{\gamma^{i,mi}\gamma^{mi,d}}\right)^{1-\eta_i}\right] + \gamma^{mi,d}i^m\right\}\hat{\gamma}_t^{mi,d} \\
&+i^m\left(\gamma^{mi,d}-\frac{1}{\lambda^d}\right)\hat{i}_t \\
&+\frac{1}{\gamma^f}\left[\left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i}-1}\right)i^m\right]\hat{\gamma}_t^f.
\end{aligned}
\tag{C.69}
$$

Profit of exporting firms

The profit of exporting firms is defined as follows:

$$
\Pi_t^x = P_t^x\left(C_t^x + I_t^x\right) - P_t^d\left(C_t^x + I_t^x\right). \tag{C.70}
$$

Stationarizing this expression, gives:

$$
\frac{\Pi_t^x}{P_t^d z_t} = \frac{P_t^x\left(C_t^x + I_t^x\right)}{P_t^d z_t} - \frac{P_t^d\left(C_t^x + I_t^x\right)}{P_t^d z_t}, \tag{C.71}
$$

which can be rewritten as follows:

$$
\overline{\Pi}_t^x = \left(mc_t^x\right)^{-1}\left(c_t^x + i_t^x\right) - \left(c_t^x + i_t^x\right). \tag{C.72}
$$

$$
\overline{\widetilde{\Pi}}_t^x = -\left(mc^x\right)^{-2}mc^x x\widehat{mc}_t^x + \left[\left(mc^x\right)^{-1} - 1\right]x\hat{x}_t \tag{C.73}
$$

$$
\overline{\widetilde{\Pi}}_t^x = -x\widehat{mc}_t^x \quad \text{since} \quad mc^x = 1. \tag{C.74}
$$

Imposing that the real profits for the exporting firm are zero in steady state, implies the following:

$$\overline{\Pi}^x = \frac{P^x}{P^d}x - \frac{P^d}{P^d}x - \frac{P^d}{P^d}\phi^x = 0. \tag{C.75}$$

Thus the value of ϕ^x must equal:

$$\phi^x = \left[(mc^x)^{-1} - 1\right] x. \tag{C.76}$$

$$\overline{\Pi}_t^x = (mc_t^x)^{-1}(c_t^x + i_t^x) - (c_t^x + i_t^x) - \left[(mc^x)^{-1} - 1\right] x. \tag{C.77}$$

$$\tilde{\overline{\Pi}}_t^x = -y^* \widehat{mc}_t^x. \tag{C.78}$$

Total profits

Using the derivations above, total profits can be derived as follows:

$$\begin{aligned}
\tilde{\overline{\Pi}}_t =& \tilde{\overline{\Pi}}_t^d + \tilde{\overline{\Pi}}_t^m + \tilde{\overline{\Pi}}_t^x \\
=& y\left(\frac{\lambda^d - 1}{\lambda^d}\right)\hat{y}_t - \frac{1}{\lambda^d}\left(y + \phi^d\right)\widehat{mc}_t^d \\
& + c^m\left(\gamma^{mc,d} - \gamma^x\right)\hat{c}_t^m + i^m\left(\gamma^{mi,d} - \gamma^x\right)\hat{i}_t^m + \gamma^{mc,d}c^m\hat{\gamma}_t^{mc,d} \\
& + \gamma^{mi,d}i^m\hat{\gamma}_t^{mi,d} - \gamma^x\left[\left(\frac{\eta^{m,c}}{\eta^{m,c} - 1}\right)c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i} - 1}\right)i^m\right]\hat{\gamma}_t^x \\
& - y^*\widehat{mc}_t^x
\end{aligned} \tag{C.79}$$

Further, noting that $\gamma^x = \frac{1}{\gamma^f}$ and $\hat{\gamma}_t^x = -\hat{\gamma}_t^f$, and using the definitions of $\hat{y}_t$, $\widehat{mc}_t$, $\hat{c}_t^m$ and $\hat{i}_t^m$, it is possible to obtain:

$$\begin{aligned}
\tilde{\overline{\Pi}}_t =& \tilde{\overline{\Pi}}_t^d + \tilde{\overline{\Pi}}_t^m + \tilde{\overline{\Pi}}_t^x \\
=& y\left(\frac{\lambda^d - 1}{\lambda^d}\right)\left(\lambda^d(1-\alpha)\hat{H}_t + \lambda^d\alpha\left(\hat{k}_t - \hat{\mu}_{z,t}\right) + \lambda^d\hat{\epsilon}_t\right) \\
& - \frac{1}{\lambda^d}\left(y + \phi^d\right)\left(\alpha\left(\hat{\mu}_{z,t} + \hat{H}_t - \hat{k}_t\right) + \hat{\bar{w}}_t + \hat{R}_t^f - \hat{\epsilon}_t\right) \\
& + c^m\left(\gamma^{mc,d} - \gamma^x\right)\left(\eta_c\hat{\gamma}_t^{c,mc} + \hat{c}_t\right) \\
& + i^m\left(\gamma^{mi,d} - \gamma^x\right)\left(\eta_i\hat{\gamma}_t^{i,mi} + \hat{i}_t\right) \\
& + \gamma^{mc,d}c^m\hat{\gamma}_t^{mc,d} + \gamma^{mi,d}i^m\hat{\gamma}_t^{mi,d} \\
& - \frac{1}{\gamma^f}\left[\left(\frac{\eta^{m,c}}{\eta^{m,c} - 1}\right)c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i} - 1}\right)i^m\right]\hat{\gamma}_t^f \\
& - y^*\widehat{mc}_t^x.
\end{aligned} \tag{C.80}$$

This can be further rewritten as follows:

$$
\begin{aligned}
\widetilde{\widetilde{\Pi}}_t =& \widetilde{\widetilde{\Pi}}_t^d + \widetilde{\widetilde{\Pi}}_t^m + \widetilde{\widetilde{\Pi}}_t^x \\
=& y\left(\frac{\lambda^d-1}{\lambda^d}\right)\lambda^d\left(1-\alpha\right)\hat{H}_t + y\left(\frac{\lambda^d-1}{\lambda^d}\right)\lambda^d\alpha\hat{k}_t - y\left(\frac{\lambda^d-1}{\lambda^d}\right)\lambda^d\alpha\hat{\mu}_{z,t} \\
&+ y\left(\frac{\lambda^d-1}{\lambda^d}\right)\lambda^d\hat{\epsilon}_t \\
&- \frac{1}{\lambda^d}\left(y+\phi^d\right)\alpha\hat{\mu}_{z,t} - \frac{1}{\lambda^d}\left(y+\phi^d\right)\alpha\hat{H}_t + \frac{1}{\lambda^d}\left(y+\phi^d\right)\alpha\hat{k}_t \\
&- \frac{1}{\lambda^d}\left(y+\phi^d\right)\hat{\bar{w}}_t - \frac{1}{\lambda^d}\left(y+\phi^d\right)\hat{R}_t^f + \frac{1}{\lambda^d}\left(y+\phi^d\right)\hat{\epsilon}_t \\
&+ c^m\left(\gamma^{mc,d} - \frac{1}{\gamma^f}\right)\eta_c\left(-\left(1-\omega_c\right)\left(\frac{1}{\gamma^{c,mc}\gamma^{mc,d}}\right)^{1-\eta_c}\right)\hat{\gamma}_t^{mc,d} \\
&+ c^m\left(\gamma^{mc,d} - \frac{1}{\gamma^f}\right)\hat{c}_t \\
&+ i^m\left(\gamma^{mi,d} - \frac{1}{\gamma^f}\right)\eta_i\left(-\left(1-\omega_i\right)\left(\frac{1}{\gamma^{i,mi}\gamma^{mi,d}}\right)^{1-\eta_i}\right)\hat{\gamma}_t^{mi,d} \\
&+ i^m\left(\gamma^{mi,d} - \frac{1}{\gamma^f}\right)\hat{i}_t \\
&+ \gamma^{mc,d}c^m\hat{\gamma}_t^{mc,d} + \gamma^{mi,d}i^m\hat{\gamma}_t^{mi,d} \\
&- \frac{1}{\gamma^f}\left[\left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i}-1}\right)i^m\right]\hat{\gamma}_t^f \\
&- y^*\widehat{mc}_t^x
\end{aligned}
\tag{C.81}
$$

or:

$$
\begin{aligned}
\tilde{t}_t^f =& \widetilde{\widetilde{\Pi}}_t = \widetilde{\widetilde{\Pi}}_t^d + \widetilde{\widetilde{\Pi}}_t^m + \widetilde{\widetilde{\Pi}}_t^x \\
=& y\left(\frac{\lambda^d-1}{\lambda^d}\right)\hat{y}_t - \frac{1}{\lambda^d}\left(\alpha\left(\hat{\mu}_{z,t} + \hat{H}_t - \hat{k}_t\right) + \hat{\bar{w}}_t + \hat{R}_t^f - \hat{\epsilon}_t\right) \\
&+ \left[c^m\left(\gamma^{mc,d} - \frac{1}{\gamma^f}\right)\eta_c\left(-\left(1-\omega_c\right)\left(\frac{1}{\gamma^{c,mc}\gamma^{mc,d}}\right)^{1-\eta_c}\right) + \gamma^{mc,d}c^m\right]\hat{\gamma}_t^{mc,d} \\
&+ c^m\left(\gamma^{mc,d} - \frac{1}{\gamma^f}\right)\hat{c}_t \\
&+ \left[i^m\left(\gamma^{mi,d} - \frac{1}{\gamma^f}\right)\eta_i\left(-\left(1-\omega_i\right)\left(\frac{1}{\gamma^{i,mi}\gamma^{mi,d}}\right)^{1-\eta_i}\right) + \gamma^{mi,d}i^m\right]\hat{\gamma}_t^{mi,d} \\
&+ i^m\left(\gamma^{mi,d} - \frac{1}{\gamma^f}\right)\hat{i}_t \\
&- \frac{1}{\gamma^f}\left[\left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i}-1}\right)i^m\right]\hat{\gamma}_t^f \\
&- y^*\widehat{mc}_t^x.
\end{aligned}
\tag{C.82}
$$

Total tax revenue

$$\hat{t}_t = \frac{\tau^c t^a}{t}\hat{t}_t^a + \frac{\tau^y t^b}{t}\hat{t}_t^b + \frac{\tau^k}{t}\left(\tilde{t}_t^c + \tilde{t}_t^d + \tilde{t}_t^e + \tilde{t}_t^f\right). \tag{C.83}$$

Appendix D. Complete model in log-linearized form (the baseline model specification)

This appendix presents the log-linearized equations of the model. In what follows, a variable with a hat denotes the log deviation from steady-state values ($\hat{x}_t = \frac{x_t - x}{x} \approx \ln x_t - \ln x$ for any variable x_t, where x is the steady-state level), while the overhead tilde indicates that a variable is measured as difference from its steady-state value, i.e. $\tilde{x}_t \equiv x_t - x$. Because the model comprises the unit-root technology shock, all real variables have to be scaled with the trend level of technology z_t in order to render them stationary. The resulting stationary variables are denoted by lower-case letters, that is, $x_t = \frac{X_t}{z_t}$.

Domestic Phillips curve:

$$\hat{\pi}_t^d = \frac{\beta}{1+\beta\kappa_d}\mathbb{E}_t\hat{\pi}_{t+1}^d + \frac{\kappa_d}{1+\beta\kappa_d}\hat{\pi}_{t-1}^d + \frac{(1-\xi_d)(1-\beta\xi_d)}{\xi_d(1+\beta\kappa_d)}\left(\widehat{mc}_t + \hat{\lambda}_t^d\right). \tag{D.1}$$

Phillips curve for the imported consumption goods:

$$\begin{aligned}\hat{\pi}_t^{m,c} &= \frac{\beta}{1+\beta\kappa_{m,c}}\mathbb{E}_t\hat{\pi}_{t+1}^{m,c} + \frac{\kappa_{m,c}}{1+\beta\kappa_{m,c}}\hat{\pi}_{t-1}^{m,c} \\ &\quad + \frac{(1-\xi_{m,c})(1-\beta\xi_{m,c})}{\xi_{m,c}(1+\beta\kappa_{m,c})}\left(\widehat{mc}_t^{m,c} + \hat{\lambda}_t^{m,c}\right).\end{aligned} \tag{D.2}$$

Real marginal cost for domestic firms:

$$\widehat{mc}_t = \alpha\hat{r}_t^k + (1-\alpha)\hat{\bar{w}}_t - \hat{\epsilon}_t \tag{D.3}$$

Rental rate of capital:

$$\hat{r}_t^k = \hat{\mu}_{z,t} + \hat{\bar{w}}_t + \hat{H}_t - \hat{k}_t \tag{D.4}$$

Phillips curve for the imported investment goods:

$$\begin{aligned}\hat{\pi}_t^{m,i} &= \frac{\beta}{1+\beta\kappa_{m,i}}\mathbb{E}_t\hat{\pi}_{t+1}^{m,i} + \frac{\kappa_{m,i}}{1+\beta\kappa_{m,i}}\hat{\pi}_{t-1}^{m,i} \\ &\quad + \frac{(1-\xi_{m,i})(1-\beta\xi_{m,i})}{\xi_{m,i}(1+\beta\kappa_{m,i})}\left(\widehat{mc}_t^{m,i} + \hat{\lambda}_t^{m,i}\right).\end{aligned} \tag{D.5}$$

Real marginal cost for the importing firms (consumption goods):

$$\widehat{mc}_t^{m,c} = -\widehat{mc}_t^x - \hat{\gamma}_t^{x,*} - \hat{\gamma}_t^{mc,d}. \tag{D.6}$$

Real marginal cost for the importing firms (investment goods):

$$\widehat{mc}_t^{m,i} = -\widehat{mc}_t^x - \hat{\gamma}_t^{x,*} - \hat{\gamma}_t^{mi,d}. \tag{D.7}$$

Phillips curve for the exporting firms:

$$\hat{\pi}_t^x = \frac{\beta}{1+\beta\kappa_x}\mathbb{E}_t\hat{\pi}_{t+1}^x + \frac{\kappa_x}{1+\beta\kappa_x}\hat{\pi}_{t-1}^x + \frac{(1-\xi_x)(1-\beta\xi_x)}{\xi_x(1+\beta\kappa_x)}\left(\widehat{mc}_t^x + \hat{\lambda}_t^x\right). \tag{D.8}$$

Real marginal cost for the exporting firms:

$$\widehat{mc}_t^x = \widehat{mc}_{t-1}^x + \hat{\pi}_t^d - \hat{\pi}_t^x. \tag{D.9}$$

Real wage equation:

$$\mathbb{E}_t\left[\begin{array}{c} \alpha_0\hat{\bar{w}}_{t-1} + \alpha_1\hat{\bar{w}}_t + \alpha_2\hat{\bar{w}}_{t+1} + \alpha_3\left(\hat{\pi}_t^d - \hat{\bar{\pi}}_t^c\right) + \alpha_4\left(\hat{\pi}_{t+1}^d - \rho_{\bar{\pi}^c}\hat{\bar{\pi}}_t^c\right) \\ +\alpha_5\left(\hat{\pi}_{t-1}^c - \hat{\bar{\pi}}_t^c\right) + \alpha_6\left(\hat{\pi}_t^c - \rho_{\bar{\pi}^c}\hat{\bar{\pi}}_t^c\right) \\ +\alpha_7\hat{\psi}_{z,t} + \alpha_8\hat{H}_t + \alpha_9\hat{\zeta}_t^h + \alpha_{10}\hat{\tau}_t^b \end{array}\right] = 0, \tag{D.10}$$

where:

$$\begin{pmatrix} \alpha_0 \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \\ \alpha_7 \\ \alpha_8 \\ \alpha_9 \\ \alpha_{10} \end{pmatrix} = \begin{pmatrix} b_w\xi_w \\ \sigma_L\lambda_w - b_w\left(1+\beta\xi_w^2\right) \\ b_w\beta\xi_w \\ -b_w\xi_w \\ b_w\beta\xi_w \\ b_w\xi_w\kappa_w \\ -b_w\beta\xi_w\kappa_w \\ (1-\lambda_w) \\ -(1-\lambda_w)\sigma_L \\ -(1-\lambda_w) \\ (1-\lambda_w)\dfrac{\tau^b}{(1-\tau^y+\tau^b)} \end{pmatrix}$$

and:

$$b_w = \frac{[\lambda_w\sigma_L - (1-\lambda_w)]}{[(1-\beta\xi_w)(1-\xi_w)]}.$$

Euler equation for consumption:

$$\mathbb{E}_t\left[\begin{array}{c} -b\beta\hat{c}_{t+1} + \left(\mu_t^2 + b^2\beta\right)\hat{c}_t - b\mu_z\hat{c}_{t-1} + b\mu_z\left(\hat{\mu}_{z,t} - \beta\hat{\mu}_{z,t+1}\right) \\ +(\mu_z - b\beta)(\mu_z - b)\hat{\psi}_{z,t} + (\mu_z - b\beta)(\mu_z - b)\hat{\gamma}_t^{c,d} \\ -(\mu_z - b)\left(\mu_z\hat{\zeta}_t^c - b\beta\hat{\zeta}_{t+1}^c\right) \end{array}\right] = 0. \tag{D.11}$$

First order condition w.r.t. i_t:

$$\mathbb{E}_t\left\{\hat{P}_{k',t} + \hat{\Upsilon}_t - \mu_z^2\tilde{S}''\left[\left(\hat{i}_t - \hat{i}_{t-1}\right) - \beta\left(\hat{i}_{t+1} - \hat{i}_t\right) + \hat{\mu}_{z,t} - \beta\hat{\mu}_{z,t+1}\right]\right\} = 0. \tag{D.12}$$

First order condition w.r.t. b_{t+1}:

$$\mathbb{E}_t \left[\begin{array}{c} -\hat{\psi}_{z,t} + \dfrac{\pi\mu_z - \tau^k\beta}{\mu_z\pi} \left(\hat{\psi}_{z,t+1} - \hat{\mu}_{z,t+1} - \hat{\pi}^d_{t+1} + \hat{R}_t \right) \\ +\beta \dfrac{\tau^k}{\mu_z\pi} \left(\hat{\psi}_{z,t+1} - \hat{\mu}_{z,t+1} - \hat{\pi}^d_{t+1} \right) \end{array} \right] = 0. \tag{D.13}$$

First order condition w.r.t. $\bar{k}_{t+1}$:

$$\mathbb{E}_t \left[\hat{\psi}_{z,t} + \hat{\mu}_{z,t+1} - \hat{\psi}_{z,t+1} - \frac{\beta(1-\delta)}{\mu_z} \hat{P}_{k',t+1} + \hat{P}_{k',t} - \frac{\mu_z - \beta(1-\delta)}{\mu_z} \hat{r}^k_{t+1} \right] = 0. \tag{D.14}$$

Law of motion for capital:

$$\hat{\bar{k}}_{t+1} = (1-\delta)\frac{1}{\mu_z}\hat{\bar{k}}_t - (1-\delta)\frac{1}{\mu_z}\hat{\mu}_{z,t} + \left[1 - (1-\delta)\frac{1}{\mu_z}\right]\hat{\Upsilon}_t + \left[1 - (1-\delta)\frac{1}{\mu_z}\right]\hat{i}_t. \tag{D.15}$$

Capacity utilization rate:

$$\hat{u}_t = \hat{k}_t - \hat{\bar{k}}_t = \frac{1}{\sigma_a}\hat{r}^k_t. \tag{D.16}$$

Aggregate resource constraint:

$$\begin{aligned} (1-\omega_c)\left(\gamma^{c,d}\right)^{\eta_c}\frac{c}{y}\left(\hat{c}_t + \eta_c\hat{\gamma}^{c,d}_t\right) + (1-\omega_i)\left(\gamma^{i,d}\right)^{\eta_i}\frac{i}{y}\left(\hat{i}_t + \eta_i\hat{\gamma}^{i,d}_t\right) + \frac{g}{y}\hat{g}_t \\ +\frac{y^*}{y}\left(\hat{y}^*_t - \eta_f\hat{\gamma}^{x,*}_t + \hat{\tilde{z}}^*_t\right) \\ = \lambda^d\left[\hat{\epsilon}_t + \alpha\left(\hat{k}_t - \hat{\mu}_{z,t}\right) + (1-\alpha)\hat{H}_t\right] \\ -\left(1-\tau^k\right)r^k\frac{\bar{k}}{y}\frac{1}{\mu_z}\left(\hat{k}_t - \hat{\bar{k}}_t\right). \end{aligned} \tag{D.17}$$

Equilibrium law of motion for net foreign assets:

$$\begin{aligned} \hat{a}_t = & -y^*\widehat{mc}^x_t - \eta_f y^*\hat{\gamma}^{x,*}_t + y^*\hat{y}^*_t + y^*\hat{\tilde{z}}^*_t + (c^m + i^m)\hat{\gamma}^f_t \\ & -c^m\left[-\eta_c(1-\omega_c)\left(\gamma^{c,d}\right)^{-(1-\eta_c)}\hat{\gamma}^{mc,d}_t + \hat{c}_t\right] \\ & +i^m\left[-\eta_i(1-\omega_i)\left(\gamma^{i,d}\right)^{-(1-\eta_i)}\hat{\gamma}^{mi,d}_t + \hat{i}_t\right] + \frac{R}{\pi\mu_z}\hat{a}_{t-1}. \end{aligned} \tag{D.18}$$

CPI inflation:

$$\hat{\pi}^c_t = \left[(1-\omega_c)\left(\gamma^{d,c}\right)^{1-\eta_c}\right]\hat{\pi}^d_t + \left[(\omega_c)\left(\gamma^{mc,c}\right)^{1-\eta_c}\right]\hat{\pi}^{m,c}_t. \tag{D.19}$$

Investment price inflation:

$$\hat{\pi}_t^i = \left[(1-\omega_i)\left(\gamma^{d,i}\right)^{1-\eta_i}\right]\hat{\pi}_t^d + \left[(\omega_i)\left(\gamma^{mi,i}\right)^{1-\eta_i}\right]\hat{\pi}_t^{m,i}. \tag{D.20}$$

Consumption deflator inflation:

$$\begin{aligned}
\hat{\pi}_t^{def,c} &= \frac{c^d}{c^d + \frac{\eta^{m,c}}{\eta^{m,c}-1}c^m}\hat{\pi}_t^d \\
&+ \frac{c^m}{c^d + \frac{\eta^{m,c}}{\eta^{m,c}-1}c^m}\frac{\eta^{m,c}}{\eta^{m,c}-1}\hat{\pi}_t^{m,c} \\
&+ \left\{\begin{array}{c} \dfrac{\left(1-\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)c^m c^d}{\left(c^d+c^m\right)\left(c^d+\frac{\eta^{m,c}}{\eta^{m,c}-1}c^m\right)}\eta_c\omega_c\left(\gamma^{c,mc}\right)^{-(1-\eta_c)} \\ -\dfrac{\left(\frac{\eta^{m,c}}{\eta^{m,c}-1}-1\right)c^d c^m}{\left(c^d+c^m\right)\left(c^d+\frac{\eta^{m,c}}{\eta^{m,c}-1}c^m\right)}\eta_c\left(1-\omega_c\right)\left(\gamma^{c,d}\right)^{-(1-\eta_c)} \end{array}\right\}\Delta\hat{\gamma}_t^{mc,d}.
\end{aligned} \tag{D.21}$$

Investment deflator inflation:

$$\begin{aligned}
\hat{\pi}_t^{def,i} &= \frac{i^d}{i^d + \frac{\eta^{m,i}}{\eta^{m,i}-1}i^m}\hat{\pi}_t^d \\
&+ \frac{i^m}{i^d + \frac{\eta^{m,i}}{\eta^{m,i}-1}i^m}\frac{\eta^{m,i}}{\eta^{m,i}-1}\hat{\pi}_t^{m,i} \\
&+ \left\{\begin{array}{c} \dfrac{\left(1-\frac{\eta^{m,i}}{\eta^{m,i}-1}\right)i^m i^d}{\left(i^d+i^m\right)\left(i^d+\frac{\eta^{m,i}}{\eta^{m,i}-1}i^m\right)}\eta_i\omega_i\left(\gamma^{i,mi}\right)^{-(1-\eta_i)} \\ -\dfrac{\left(\frac{\eta^{m,i}}{\eta^{m,i}-1}-1\right)i^d i^m}{\left(i^d+i^m\right)\left(i^d+\frac{\eta^{m,i}}{\eta^{m,i}-1}i^m\right)}\eta_i\left(1-\omega_i\right)\left(\gamma^{i,d}\right)^{-(1-\eta_i)} \end{array}\right\}\Delta\hat{\gamma}_t^{mi,d}.
\end{aligned} \tag{D.22}$$

Gross domestic product:

$$\hat{y}_t = \lambda^d\left[\hat{\epsilon}_t + \alpha\left(\hat{k}_t - \hat{\mu}_{z,t}\right) + (1-\alpha)\hat{H}_t\right]. \tag{D.23}$$

Real effective exchange rate:

$$\hat{x}_t = -\omega_c\left(\gamma^{c,mc}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} - \hat{\gamma}_t^{x,*} - \widehat{mc}_t^x. \tag{D.24}$$

Employment equation:

$$\Delta\hat{E}_t = \frac{\beta}{1+\beta}\mathbb{E}_t\Delta\hat{E}_{t+1} + \frac{(1-\xi_e)(1-\beta\xi_e)}{(1+\beta)\xi_e}\left(\hat{H}_t - \hat{E}_t\right). \tag{D.25}$$

Domestic interest rate:

$$\hat{R}_t = \hat{R}_t^* + \hat{\tilde{\phi}}_t - \tilde{\phi}_a \hat{a}_t. \tag{D.26}$$

Government budget constraint:

$$b\hat{b}_t + t\hat{t}_t = \frac{Rb}{\pi^d \mu_z}\left(\hat{R}_{t-1} + \hat{b}_{t-1} - \hat{\pi}_t^d - \hat{\mu}_{z,t}\right) + tr\widehat{tr}_t + g\hat{g}_t. \tag{D.27}$$

Government expenditures:

$$\widehat{gex}_t = \frac{tr}{gex}\widehat{tr}_t + \frac{g}{gex}\hat{g}_t + \frac{r}{gex}\frac{R}{\pi\mu_z(R-1)}\hat{R}_{t-1} + \frac{r}{gex}\frac{\hat{b}_{t-1}}{\pi\mu_z} - \frac{r}{gex}\frac{\hat{\pi}_t}{\pi\mu_z} - \frac{r}{gex}\frac{\hat{\mu}_{z,t}}{\pi\mu_z}. \tag{D.28}$$

Transfers to households:

$$\widehat{tr}_t = \hat{\tau}_t^{tr} + \hat{\bar{w}}_t + \hat{H}_t. \tag{D.29}$$

Fiscal policy rule for government consumption:

$$\hat{g}_t = \rho_g \hat{g}_{t-1} - \phi_\pi \hat{\pi}_t^c - \phi_y \hat{y}_t - \phi_b \hat{b}_t - \phi_d \widetilde{def}_t + \varepsilon_{g,t}. \tag{D.30}$$

Tax on consumption:

$$\hat{t}_t^a = \omega_c \left(\gamma^{c,mc}\right)^{-(1-\eta_c)} \hat{\gamma}_t^{mc,d} + \hat{c}_t. \tag{D.31}$$

Taxes and contributions on wages:

$$\hat{t}_t^b = \hat{\bar{w}}_t + \hat{H}_t. \tag{D.32}$$

Public debt interest payments:

$$\tilde{t}_t^c = \frac{Rb}{\pi\mu_z}\hat{R}_{t-1} + \frac{(R-1)\,b}{\pi\mu_z}\hat{b}_{t-1} - \frac{(R-1)\,b}{\pi\mu_z}\hat{\pi}_t - \frac{(R-1)\,b}{\pi\mu_z}\hat{\mu}_{z,t}. \tag{D.33}$$

Interest on the amount of the capital services:

$$\tilde{t}_t^d = \frac{r^k k}{\mu_z}\left(\hat{r}_t^k + \hat{k}_t - \hat{\mu}_{z,t}\right). \tag{D.34}$$

Interest on the amount of foreign bond holdings:

$$\tilde{t}_t^e = \frac{R-1}{\pi\mu_z}\tilde{a}_{t-1}. \tag{D.35}$$

Profit of domestic firms:

$$\tilde{\overline{\Pi}}_t^d = y\left(\frac{\lambda^d - 1}{\lambda^d}\right)\hat{y}_t - \frac{1}{\lambda^d}(y+\phi)\left[\alpha\left(\hat{\mu}_{z,t} + \hat{H}_t - \hat{k}_t\right) + \hat{\bar{w}}_t - \hat{\epsilon}_t\right]. \tag{D.36}$$

Profit of importing firms:

$$
\begin{aligned}
\widetilde{\overline{\Pi}}_t^m = & \left\{ c^m \left(\gamma^{mc,d} - \frac{1}{\lambda^d} \right) \eta_c \left[-(1-\omega_c) \left(\frac{1}{\gamma^{c,mc}\gamma^{mc,d}} \right)^{1-\eta_c} \right] + \gamma^{mc,d} c^m \right\} \hat{\gamma}_t^{mc,d} \\
& + c^m \left(\gamma^{mc,d} - \frac{1}{\lambda^d} \right) \hat{c}_t \\
& + \left\{ i^m \left(\gamma^{mi,d} - \frac{1}{\lambda^d} \right) \eta_i \left[-(1-\omega_i) \left(\frac{1}{\gamma^{i,mi}\gamma^{mi,d}} \right)^{1-\eta_i} \right] + \gamma^{mi,d} i^m \right\} \hat{\gamma}_t^{mi,d} \\
& + i^m \left(\gamma^{mi,d} - \frac{1}{\lambda^d} \right) \hat{i}_t \\
& + \frac{1}{\gamma^f} \left[\left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right) c^m + \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right) i^m \right] \hat{\gamma}_t^f .
\end{aligned} \tag{D.37}
$$

Profit of exporting firms:

$$\widetilde{\overline{\Pi}}_t^x = -y^* \widehat{mc}_t^x . \tag{D.38}$$

Total tax revenue:

$$\hat{t}_t = \frac{\tau^c t^a}{t} \hat{t}_t^a + \frac{\tau^y t^b}{t} \hat{t}_t^b + \frac{\tau^k}{t} \left(\tilde{t}_t^c + \tilde{t}_t^d + \tilde{t}_t^e + \tilde{t}_t^f \right). \tag{D.39}$$

Deficit:

$$\widetilde{def}_t = gex\widehat{gex}_t - t\hat{t}_t . \tag{D.40}$$

Debt-to-GDP ratio:

$$\hat{b}_{y,t} = \hat{b}_t - \hat{y}_t . \tag{D.41}$$

Deficit-to-GDP ratio:

$$\widetilde{def}_{y,t} = \frac{\widetilde{def}_t}{y} - \frac{def}{y} \hat{y}_t . \tag{D.42}$$

Relative prices:

$$\hat{\gamma}_t^{mc,d} = \hat{\gamma}_{t-1}^{mc,d} + \hat{\pi}_t^{m,c} - \hat{\pi}_t^d \tag{D.43}$$

$$\hat{\gamma}_t^{mi,d} = \hat{\gamma}_{t-1}^{mi,d} + \hat{\pi}_t^{m,i} - \hat{\pi}_t^d \tag{D.44}$$

$$\hat{\gamma}_t^{x,*} = \hat{\gamma}_{t-1}^{x,*} + \hat{\pi}_t^x - \hat{\pi}_t^* \tag{D.45}$$

$$\hat{\gamma}_t^f = \widehat{mc}_t^x + \hat{\gamma}_t^{x,*} \tag{D.46}$$

$$\hat{\gamma}_t^{c,d} = \omega_c \left(\gamma^{mc,c}\right)^{(1-\eta_c)} \hat{\gamma}_t^{mc,d} \tag{D.47}$$

$$\hat{\gamma}_t^{i,d} = \omega_i \left(\gamma^{mi,i}\right)^{(1-\eta_i)} \hat{\gamma}_t^{mi,d}. \tag{D.48}$$

Exogenous shock processes:

$$\hat{\xi}_t = \rho_\xi \hat{\xi}_{t-1} + \varepsilon_{\xi,t}, \quad \varepsilon_{\xi,t} \overset{iid}{\sim} N\left(0, \sigma_\xi^2\right), \tag{D.49}$$

where $\xi_t = \left\{\mu_{z,t}, \epsilon_t, \lambda_t^j, \zeta_t^c, \zeta_t^h, \Upsilon_t, \tilde{\phi}_t, \tilde{z}_t^*, \tau_t^{tr}, g_t\right\}$ for $j = \{d, mc, mi, x\}$.

Appendix E. Data sources and description

Table E.1: *List of variables used in the estimation and their sources*

Symbol	*Description*	*Country*	*Source*
Y_t	*GDP.* Gross domestic product in millions of euro, chain-linked volumes, reference year 2005, SA	SI	Eurostat
C_t	*Private consumption.* Household and NPISH final consumption expenditure in millions of euro, chain-linked volumes, reference year 2005, SA	SI	Eurostat
I_t	*Investment.* Gross fixed capital formation in millions of euro, chain-linked volumes, reference year 2005, SA	SI	Eurostat
G_t	*Government consumption.* Final consumption expenditure of general government in millions of euro, chain-linked volumes, reference year 2005, SA	SI	Eurostat
X_t	*Exports.* Exports of goods and services in millions of euro, chain-linked volumes, reference year 2005, SA	SI	Eurostat
M_t	*Imports.* Imports of goods and services in millions of euro, chain-linked volumes, reference year 2005, SA	SI	Eurostat
W_t	*Gross wages and salaries.* Gross wages and salaries (income structure of GDP), current prices, millions of euro, SA	SI	SORS
E_t	*Employment.* Employment (domestic concept), persons (in 1000), SA	SI	SORS
P_t^d	*GDP deflator.* Price index, reference year 2005, SA	SI	Eurostat
P_t^c	*CPI index.* Consumer price index, current month/average of the year 2005, not SA	SI	Eurostat/ECB
x_t	*Real exchange rate.* Real effective exchange rate, consumer price index deflator, reference year 2005, 28 trading partners	SI	Eurostat
R_t	*Domestic interest rate.* Monetary interest rate on new loans to non-financial corporations in domestic currency in percent	SI	BS/IMAD
Y_t^*	*Foreign GDP.* Gross domestic product in millions of euro, chain-linked volumes, reference year 2005, SA	EA12	Eurostat
P_t^*	*Foreign GDP deflator.* Price index, reference year 2005, SA	EA12	Eurostat
R_t^*	*Foreign interest rate.* 12-month money market interest rate in percent	EA12	Eurostat

Notes: SA: seasonally adjusted; SORS: Statistical Office of the Republic of Slovenia; IMAD: Institute of Macroeconomic Analysis and Development of the Republic of Slovenia; BS: Bank of Slovenia

Source: Own work.

Appendix F. Measurement equations

This appendix presents the measurement equations that are employed to relate the model variables to the observed data. When specifying the measurement equations, I closely follow the paper of Adolfson et al. (2008) and that of Pfeifer (2014).[64] I include 16 key macroeconomic quarterly Slovenian variables as observables in the estimation procedure. All real variables are used in growth rates (first differences in logs, $\Delta \ln$), whereas the remaining variables are used in levels. Since the model is at a quarterly frequency, the model's variables for domestic and

[64] This paper provides a comprehensive theoretical background to specifying measurement equations for estimating DSGE models.

foreign interest rate are multiplied by 4[65] in order to match them to the annualized data series for these variables. In what follows, $\ln \mu_z$ is the common quarterly trend growth rate to real GDP, private consumption, investment, exports, imports, government consumption and the real wage. Further, π denotes the quarterly steady state gross inflation rate, and R is the quarterly steady state gross nominal interest rate.

Domestic inflation

$$\pi_t^{d,data} = (\pi - 1) + \hat{\pi}_t^d \tag{F.1}$$

Real wage

$$\Delta \ln W_t^{data} = \ln \mu_z + \Delta \hat{\bar{w}}_t + \hat{\mu}_{z,t} \tag{F.2}$$

Change in real consumption

The relative price between aggregate consumption and domestic goods is defined as:

$$\begin{aligned} \gamma_t^{c,d} = \frac{P_t^c}{P_t^d} &= \left[(1 - \omega_c) + \omega \left(\frac{P_t^{m,c}}{P_t^d} \right)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}} \\ &= \left[(1 - \omega_c) + \omega \left(\gamma_t^{mc,d} \right)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}}. \end{aligned} \tag{F.3}$$

Differentiating this with respect to $\gamma_t^{c,d}$ and $\gamma_t^{mc,d}$, gives:

$$\frac{\partial \gamma_t^{c,d}}{\partial \gamma_t^{c,d}} = 1 \tag{F.4}$$

and:

$$\frac{\partial \gamma_t^{c,d}}{\partial \gamma_t^{mc,d}} = \frac{1}{1 - \eta_c} \left[(1 - \omega_c) + \omega \left(\gamma_t^{mc,d} \right)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c} - 1} \omega_c \left(1 - \eta_c \right) \left(\gamma^{mc,d} \right)^{-\eta_c}. \tag{F.5}$$

The Taylor expansion follows:

$$\begin{aligned} \gamma^{c,d} \hat{\gamma}_t^{c,d} =& \gamma^{mc,d} \frac{1}{1 - \eta_c} \left[(1 - \omega_c) + \omega \left(\gamma_t^{mc,d} \right)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c} - 1} \omega_c \left(1 - \eta_c \right) \left(\gamma^{mc,d} \right)^{-\eta_c} \hat{\gamma}_t^{mc,d} \\ =& \left[(1 - \omega_c) + \omega \left(\gamma_t^{mc,d} \right)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c} - 1} \omega_c \left(\gamma^{mc,d} \right)^{1-\eta_c} \hat{\gamma}_t^{mc,d} \\ =& \left[\left(\gamma^{c,d} \right)^{1-\eta_c} \right]^{\frac{\eta_c}{1-\eta_c}} \omega_c \left(\gamma^{mc,d} \right)^{1-\eta_c} \hat{\gamma}_t^{mc,d}. \end{aligned} \tag{F.6}$$

[65]Note that this is just an approximation of the correct geometric mean:

$$R_t^{obs} = \left(1 + \frac{R_t^{data}}{100} \right)^{\frac{1}{4}}.$$

Solving for $\hat{\gamma}_t^{c,d}$:

$$\begin{aligned}
\hat{\gamma}_t^{c,d} =& \omega_c \left(\frac{\gamma^{mc,d}}{\gamma^{c,d}}\right)^{1-\eta_c} \hat{\gamma}_t^{mc,d} \\
=& \omega_c \left(\frac{\frac{P^{m,c}}{P^d}}{\frac{P^c}{P^d}}\right)^{1-\eta_c} \hat{\gamma}_t^{mc,d} \\
=& \omega_c \left(\frac{P^{m,c}}{P^c}\right)^{1-\eta_c} \hat{\gamma}_t^{mc,d} \\
=& \omega_c \left(\frac{1}{\frac{P^c}{P^{m,c}}}\right)^{1-\eta_c} \hat{\gamma}_t^{mc,d} \\
=& \omega_c \left(\frac{1}{\gamma^{c,mc}}\right)^{1-\eta_c} \hat{\gamma}_t^{mc,d} \\
=& \omega_c \left(\gamma^{c,mc}\right)^{-(1-\eta_c)} \hat{\gamma}_t^{mc,d}.
\end{aligned} \tag{F.7}$$

$$\hat{\gamma}_t^{d,c} = -\omega_c \left(\gamma^{c,mc}\right)^{-(1-\eta_c)} \hat{\gamma}_t^{mc,d} \tag{F.8}$$

The relative price between aggregate consumption and imported consumption goods is defined as:

$$\begin{aligned}
\gamma_t^{c,mc} = \frac{P_t^c}{P_t^{m,c}} =& \left[(1-\omega_c)\left(\frac{P_t^d}{P_t^{m,c}}\right)^{1-\eta_c} + \omega_c\right]^{\frac{1}{1-\eta_c}} \\
=& \left[(1-\omega_c)\left(\frac{1}{\gamma_t^{mc,d}}\right)^{1-\eta_c} + \omega_c\right]^{\frac{1}{1-\eta_c}}.
\end{aligned} \tag{F.9}$$

Differentiating this with respect to $\gamma_t^{c,mc}$ and $\gamma_t^{mc,d}$, one can obtain:

$$\frac{\partial \gamma_t^{c,mc}}{\partial \gamma_t^{c,mc}} = 1 \tag{F.10}$$

and:

$$\begin{aligned}
\frac{\partial \gamma_t^{c,mc}}{\partial \gamma_t^{mc,d}} =& \frac{1}{1-\eta_c}\left[(1-\omega_c)\left(\frac{1}{\gamma_t^{mc,d}}\right)^{1-\eta_c} + \omega_c\right]^{\frac{1}{1-\eta_c}-1} (1-\omega_c)(1-\eta_c)\left(\frac{1}{\gamma^{mc,d}}\right)^{-\eta_c} \frac{-1}{\left(\gamma^{mc,d}\right)^2} \\
=& \left[\left(\gamma^{c,mc}\right)^{1-\eta_c}\right]^{\frac{\eta_c}{1-\eta_c}} (1-\omega_c)\left(\frac{1}{\gamma^{mc,d}}\right)^{-\eta_c} \frac{-1}{\left(\gamma^{mc,d}\right)^2}.
\end{aligned} \tag{F.11}$$

The Taylor expansion follows:

$$\begin{aligned}
\gamma^{c,mc}\hat{\gamma}_t^{c,mc} =& \gamma^{mc,d}\left[\left(\gamma^{c,mc}\right)^{1-\eta_c}\right]^{\frac{\eta_c}{1-\eta_c}} (1-\omega_c)\left(\frac{1}{\gamma^{mc,d}}\right)^{-\eta_c} \frac{-1}{\left(\gamma^{mc,d}\right)^2}\hat{\gamma}_t^{mc,d} \\
=& -\left(\gamma^{c,mc}\right)^{\eta_c}(1-\omega_c)\left(\frac{1}{\gamma^{mc,d}}\right)^{1-\eta_c} \hat{\gamma}_t^{mc,d}.
\end{aligned} \tag{F.12}$$

Solving for $\hat{\gamma}_t^{c,mc}$:

$$
\begin{aligned}
\hat{\gamma}_t^{c,mc} &= -\left(\gamma^{c,mc}\right)^{\eta_c - 1}(1-\omega)\left(\frac{1}{\gamma^{mc,d}}\right)^{1-\eta_c}\hat{\gamma}_t^{mc,d} \\
&= -\left(\gamma^{c,mc}\right)^{-(1-\eta_c)}(1-\omega)\left(\frac{1}{\gamma^{mc,d}}\right)^{1-\eta_c}\hat{\gamma}_t^{mc,d} \\
&= -(1-\omega_c)\left(\frac{1}{\gamma^{c,mc}\gamma^{mc,d}}\right)^{1-\eta_c}\hat{\gamma}_t^{mc,d} \\
&= -(1-\omega_c)\left(\frac{1}{\frac{P^c}{P^{m,c}}\frac{P^{m,c}}{P^d}}\right)^{1-\eta_c}\hat{\gamma}_t^{mc,d} \\
&= -(1-\omega_c)\left(\frac{1}{\frac{P^c}{P^d}}\right)^{1-\eta_c}\hat{\gamma}_t^{mc,d} \\
&= -(1-\omega_c)\left(\frac{P^d}{P^c}\right)^{1-\eta_c}\hat{\gamma}_t^{mc,d} \\
&= -(1-\omega_c)\left(\frac{P^c}{P^d}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} \\
&= -(1-\omega_c)\left(\gamma^{c,d}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d}.
\end{aligned}
\tag{F.13}
$$

In the data one can observe:

$$\tilde{C}_t \equiv C_t^d + C_t^m, \tag{F.14}$$

but in the theoretical model C_t is a CES aggregate of the two sub-components C_t^d and C_t^m. Consequently, C_t must be adjusted with the appropriate relative prices:

$$\tilde{C}_t \equiv C_t^d + C_t^m = \left[(1-\omega_c)\left(\frac{P_t^d}{P_t^c}\right)^{-\eta_c} + \omega_c\left(\frac{P_t^{m,c}}{P_t^c}\right)^{-\eta_c}\right]C_t. \tag{F.15}$$

Log-linearizing this, yields:

$$
\begin{aligned}
\tilde{c}_t &= c_t^d + c_t^m \\
\hat{\tilde{c}}_t &\approx \frac{c^d}{c^d + c^m}\hat{c}_t^d + \frac{c^m}{c^d + c^m}\hat{c}_t^m \\
&= \frac{c^d}{c^d + c^m}\left[\eta_c\omega_c\left(\gamma^{c,mc}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} + \hat{c}_t\right] + \frac{c^m}{c^d + c^m}\left[-\eta_c\left(1-\omega_c\right)\left(\gamma^{c,d}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} + \hat{c}_t\right] \\
&= \frac{c^d}{c^d + c^m}\hat{c}_t + \frac{c^m}{c^d + c^m}\hat{c}_t + \frac{c^d}{c^d + c^m}\eta_c\omega_c\left(\gamma^{c,mc}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} \\
&- \frac{c^m}{c^d + c^m}\eta_c\left(1-\omega_c\right)\left(\gamma^{c,d}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d} \\
&= \hat{c}_t + \left[\frac{c^d}{c^d + c^m}\eta_c\omega_c\left(\gamma^{c,mc}\right)^{-(1-\eta_c)} - \frac{c^m}{c^d + c^m}\eta_c\left(1-\omega_c\right)\left(\gamma^{c,d}\right)^{-(1-\eta_c)}\right]\hat{\gamma}_t^{mc,d} \\
&= \hat{c}_t + \left[\frac{c^d}{c^d + c^m}\eta_c\omega_c\left(\gamma^{c,mc}\right)^{-1}\left(\gamma^{c,mc}\right)^{\eta_c} - \frac{c^m}{c^d + c^m}\eta_c\left(1-\omega_c\right)\left(\gamma^{c,d}\right)^{-1}\left(\gamma^{c,d}\right)^{\eta_c}\right]\hat{\gamma}_t^{mc,d} \\
&= \hat{c}_t + \left[\frac{c^d}{c^d + c^m}\eta_c\left(\gamma^{c,mc}\right)^{-1}\frac{c^d}{c} - \frac{c^m}{c^d + c^m}\eta_c\left(\gamma^{c,d}\right)^{-1}\frac{c^m}{c}\right]\hat{\gamma}_t^{mc,d}.
\end{aligned}
\tag{F.16}
$$

The observed real consumption ($\tilde{C}_t^{data}$) is assumed to be related to the model's real consumption ($\tilde{C}_t$) according to the following expression:

$$
\frac{\tilde{C}_t^{data}}{\tilde{C}_{t-1}^{data}} = \frac{\frac{\tilde{C}_t z_t}{z_t}}{\frac{\tilde{C}_{t-1} z_{t-1}}{z_{t-1}}}. \tag{F.17}
$$

Taking logarithms, gives:

$$
\ln \tilde{C}_t^{data} - \ln \tilde{C}_{t-1}^{data} = \ln \tilde{c}_t - \ln \tilde{c}_{t-1} + \ln \mu_{z,t}. \tag{F.18}
$$

Adding and substracting $\ln \tilde{c}$ and $\ln \mu_z$ from the right hand side of the above equation, it is possible to obtain:

$$
\ln \tilde{C}_t^{data} - \ln \tilde{C}_{t-1}^{data} = \ln \tilde{c}_t - \ln \tilde{c} - \left(\ln \tilde{c}_{t-1} - \ln \tilde{c}\right) + \ln \mu_{z,t} - \ln \mu_z + \ln \mu_z, \tag{F.19}
$$

which can be further rewritten as follows:

$$
\ln \tilde{C}_t^{data} - \ln \tilde{C}_{t-1}^{data} = \ln \mu_z + \hat{\tilde{c}}_t - \hat{\tilde{c}}_{t-1} + \hat{\mu}_{z,t}. \tag{F.20}
$$

Using (F.16) in the above expression, one can get:

$$
\begin{aligned}
\Delta \ln \tilde{C}_t^{data} &= \ln \mu_z + \Delta\hat{c}_t \\
&+ \left[\frac{c^d}{c^d + c^m}\eta_c\left(\gamma^{c,mc}\right)^{-1}\frac{c^d}{c} - \frac{c^m}{c^d + c^m}\eta_c\left(\gamma^{c,d}\right)^{-1}\frac{c^m}{c}\right]\Delta\hat{\gamma}_t^{mc,d} + \hat{\mu}_{z,t}.
\end{aligned}
\tag{F.21}
$$

Change in real investment

In the same way as above, it is possible to define the relative price between investment and domestic goods:

$$\begin{aligned}\gamma_t^{i,d} = \frac{P_t^i}{P_t^d} &= \left[(1-\omega_i) + \omega\left(\frac{P_t^{m,i}}{P_t^d}\right)^{1-\eta_i}\right]^{\frac{1}{1-\eta_i}} \\ &= \left[(1-\omega_i) + \omega\left(\gamma_t^{mi,d}\right)^{1-\eta_i}\right]^{\frac{1}{1-\eta_i}}\end{aligned} \tag{F.22}$$

The relative price between investment goods and imported investment goods is the following:

$$\begin{aligned}\gamma_t^{i,mi} = \frac{P_t^i}{P_t^{m,i}} &= \left[(1-\omega_i)\left(\frac{P_t^d}{P_t^{m,i}}\right)^{1-\eta_i} + \omega_i\right]^{\frac{1}{1-\eta_i}} \\ &= \left[(1-\omega_i)\left(\frac{1}{\gamma_t^{mi,d}}\right)^{1-\eta_i} + \omega_i\right]^{\frac{1}{1-\eta_i}}.\end{aligned} \tag{F.23}$$

The log-linearization gives:

$$\begin{aligned}\hat{\gamma}_t^{i,d} =& \omega_i\left(\frac{1}{\gamma^{i,mi}}\right)^{1-\eta_i}\hat{\gamma}_t^{mi,d} \\ =& \omega_i\left(\gamma^{i,mi}\right)^{-(1-\eta_i)}\hat{\gamma}_t^{mi,d}\end{aligned} \tag{F.24}$$

$$\hat{\gamma}_t^{i,mi} = -(1-\omega_i)\left(\frac{1}{\gamma^{i,mi}\gamma^{mi,d}}\right)^{1-\eta_i}\hat{\gamma}_t^{mi,d}. \tag{F.25}$$

In the data one can observe:

$$\tilde{I}_t \equiv I_t^d + I_t^m, \tag{F.26}$$

but in the theoretical model I_t is a CES aggregate of the two sub-components I_t^d and I_t^m. Consequently, I_t must be adjusted with the appropriate relative prices:

$$\tilde{I}_t \equiv I_t^d + I_t^m = \left[(1-\omega_i)\left(\frac{P_t^d}{P_t^i}\right)^{-\eta_i} + \omega_i\left(\frac{P_t^{m,i}}{P_t^i}\right)^{-\eta_i}\right] I_t. \tag{F.27}$$

Log-linearizing this, gives:

$$
\begin{aligned}
\tilde{i}_t &= i_t^d + i_t^m \\
\hat{\tilde{i}}_t &\approx \frac{i^d}{i^d+i^m}\hat{i}_t^d + \frac{i^m}{i^d+i^m}\hat{i}_t^m \\
&= \frac{i^d}{i^d+i^m}\left[\eta_i\omega_i\left(\gamma^{i,mi}\right)^{-(1-\eta_i)}\hat{\gamma}_t^{mi,d} + \hat{\tilde{i}}_t\right] + \frac{i^m}{i^d+i^m}\left[-\eta_i\left(1-\omega_i\right)\left(\gamma^{i,d}\right)^{-(1-\eta_i)}\hat{\gamma}_t^{mi,d} + \hat{\tilde{i}}_t\right] \\
&= \frac{i^d}{i^d+i^m}\hat{\tilde{i}}_t + \frac{i^m}{i^d+i^m}\hat{\tilde{i}}_t + \frac{i^d}{i^d+i^m}\eta_i\omega_i\left(\gamma^{i,mi}\right)^{-(1-\eta_i)}\hat{\gamma}_t^{mi,d} \\
&- \frac{i^m}{i^d+i^m}\eta_i\left(1-\omega_i\right)\left(\gamma^{i,d}\right)^{-(1-\eta_i)}\hat{\gamma}_t^{mi,d} \\
&= \hat{\tilde{i}}_t + \left[\frac{i^d}{i^d+i^m}\eta_i\omega_i\left(\gamma^{i,mi}\right)^{-(1-\eta_i)} - \frac{i^m}{i^d+i^m}\eta_i\left(1-\omega_i\right)\left(\gamma^{i,d}\right)^{-(1-\eta_i)}\right]\hat{\gamma}_t^{mi,d} \\
&= \hat{\tilde{i}}_t + \left[\frac{i^d}{i^d+i^m}\eta_i\omega_i\left(\gamma^{i,mi}\right)^{-1}\left(\gamma^{i,mi}\right)^{\eta_i} - \frac{i^m}{i^d+i^m}\eta_i\left(1-\omega_i\right)\left(\gamma^{i,d}\right)^{-1}\left(\gamma^{i,d}\right)^{\eta_i}\right]\hat{\gamma}_t^{mi,d} \\
&= \hat{\tilde{i}}_t + \left[\frac{i^d}{i^d+i^m}\eta_i\left(\gamma^{i,mi}\right)^{-1}\frac{i^d}{i} - \frac{i^m}{i^d+i^m}\eta_i\left(\gamma^{i,d}\right)^{-1}\frac{i^m}{i}\right]\hat{\gamma}_t^{mi,d}.
\end{aligned}
\tag{F.28}
$$

The observed real investment ($\tilde{I}_t^{data}$) is assumed to be related to the model's real investment ($\tilde{I}_t$) according to the following expression:

$$
\frac{\tilde{I}_t^{data}}{\tilde{I}_{t-1}^{data}} = \frac{\frac{\tilde{I}_t z_t}{z_t}}{\frac{\tilde{I}_{t-1} z_{t-1}}{z_{t-1}}}. \tag{F.29}
$$

Taking logarithms, it follows:

$$
\ln \tilde{I}_t^{data} - \ln \tilde{I}_{t-1}^{data} = \ln \tilde{i}_t - \ln \tilde{i}_{t-1} + \ln \mu_{z,t}. \tag{F.30}
$$

Adding and substracting $\ln \tilde{i}$ and $\ln \mu_z$ from the right hand side of the above equation, gives:

$$
\ln \tilde{I}_t^{data} - \ln \tilde{I}_{t-1}^{data} = \ln \tilde{i}_t - \ln \tilde{i} - \left(\ln \tilde{i}_{t-1} - \ln \tilde{i}\right) + \ln \mu_{z,t} - \ln \mu_z + \ln \mu_z, \tag{F.31}
$$

which can be further rewritten as follows:

$$
\ln \tilde{I}_t^{data} - \ln \tilde{I}_{t-1}^{data} = \ln \mu_z + \hat{\tilde{i}}_t - \hat{\tilde{i}}_{t-1} + \hat{\mu}_{z,t}. \tag{F.32}
$$

Using (F.28) in the above expression, yields:

$$
\begin{aligned}
\Delta \ln \tilde{I}_t^{data} = &\ln \mu_z + \Delta\hat{\tilde{i}}_t + \left[\frac{i^d}{i^d+i^m}\eta_i\left(\gamma^{i,mi}\right)^{-1}\frac{i^d}{i} - \frac{i^m}{i^d+i^m}\eta_i\left(\gamma^{i,d}\right)^{-1}\frac{i^m}{i}\right]\Delta\hat{\gamma}_t^{mi,d} \\
&+ \left(1-\tau^k\right) r^k \bar{k}\frac{1}{\mu_z}\Delta\hat{u}_t + \hat{\mu}_{z,t}.
\end{aligned}
\tag{F.33}
$$

Real exchange rate

$$
\hat{x}_t^{data} = \hat{x}_t \tag{F.34}
$$

Interest rate[66]

$$R_t^{data} = 4\left(R-1\right)R + 4R\hat{R}_t \tag{F.35}$$

Employment

$$\hat{E}_t^{data} = \hat{E}_t \tag{F.36}$$

Change in output (GDP)

The observed GDP (Y_t^{data}) is assumed to be related to the model's GDP (Y_t) according to the following expression:

$$\frac{Y_t^{data}}{Y_{t-1}^{data}} = \frac{\frac{Y_t z_t}{z_t}}{\frac{Y_{t-1} z_{t-1}}{z_{t-1}}}. \tag{F.37}$$

Taking logarithms, gives:

$$\ln Y_t^{data} - \ln Y_{t-1}^{data} = \ln y_t - \ln y_{t-1} + \ln \mu_{z,t}. \tag{F.38}$$

Adding and substracting $\ln y$ and $\ln \mu_z$ from the right hand side of the above equation, it is possible to obtain:

$$\ln Y_t^{data} - \ln Y_{t-1}^{data} = \ln y_t - \ln y - \left(\ln y_{t-1} - \ln y\right) + \ln \mu_{z,t} - \ln \mu_z + \ln \mu_z, \tag{F.39}$$

which can be further rewritten as follows:

$$\ln Y_t^{data} - \ln Y_{t-1}^{data} = \ln \mu_z + \hat{y}_t - \hat{y}_{t-1} + \hat{\mu}_{z,t} \tag{F.40}$$

or:

$$\Delta \ln Y_t^{data} = \ln \mu_z + \Delta \hat{y}_t + \hat{\mu}_{z,t}. \tag{F.41}$$

Change in real exports

In the data one can observe:

$$\tilde{X}_t \equiv C_t^x + I_t^x, \tag{F.42}$$

but in the theoretical model X_t is a CES aggregate of the two sub-components C_t^x and I_t^x. Consequently, X_t must be adjusted with the appropriate relative prices:

$$\tilde{X}_t = C_t^x + I_t^x = \left(\frac{P_t^x}{P_t^*}\right)^{-\eta_f} Y_t^*. \tag{F.43}$$

Stationarizing with the unit-root technology level z_t, yields:

$$\frac{\tilde{X}_t}{z_t} = \left(\frac{P_t^x}{P_t^*}\right)^{-\eta_f} \frac{Y_t^* z_t *}{z_t^* z_t}. \tag{F.44}$$

[66] The interest rate I match in the data is expressed in effective log-linearized annualized rates. If the nominal rate in the data fluctuates around 4 percent, and I have a steady state quarterly rate of 1 percent in the model, the gross quarterly nominal rate $R = 1.01$ and to convert into an annualized effective rate in logs I can use the formula $400\left(R-1\right)R = 400\left(1.01-1\right)1.01 = 4.04$ where the R at the end captures the "interest-on-interest" rate effect. The $4R\hat{R}_t$, where $\hat{R}_t$ are the quarterly variations on the nominal rate, captures the annualization and the "interest-on-interest" effect.

Log-linearizing this, gives:

$$\hat{\tilde{x}}_t = -\eta_f \hat{\gamma}_t^{x,*} + \hat{y}_t^* + \hat{\tilde{z}}_t^*. \tag{F.45}$$

The observed real exports ($\tilde{X}_t^{data}$) is assumed to be related to the model's real exports ($\tilde{X}_t$) according to the following expression:

$$\frac{\tilde{X}_t^{data}}{\tilde{X}_{t-1}^{data}} = \frac{\frac{\tilde{X}_t z_t}{z_t}}{\frac{\tilde{X}_{t-1} z_{t-1}}{z_{t-1}}}. \tag{F.46}$$

Taking logarithms, gives:

$$\ln \tilde{X}_t^{data} - \ln \tilde{X}_{t-1}^{data} = \ln \tilde{x}_t - \ln \tilde{x}_{t-1} + \ln \mu_{z,t}. \tag{F.47}$$

Adding and substracting $\ln \tilde{x}$ and $\ln \mu_z$ from the right hand side of the above equation, gives:

$$\ln \tilde{X}_t^{data} - \ln \tilde{X}_{t-1}^{data} = \ln \tilde{x}_t - \ln \tilde{x} - (\ln \tilde{x}_{t-1} - \ln \tilde{x}) + \ln \mu_{z,t} - \ln \mu_z + \ln \mu_z, \tag{F.48}$$

which can be further rewritten as follows:

$$\ln \tilde{X}_t^{data} - \ln \tilde{X}_{t-1}^{data} = \ln \mu_z + \hat{\tilde{x}}_t - \hat{\tilde{x}}_{t-1} + \hat{\mu}_{z,t}. \tag{F.49}$$

Using (F.45) in the above expression, yields:

$$\Delta \ln \tilde{X}_t^{data} = \ln \mu_z + \Delta \left[\hat{y}_t^* - \eta_f \hat{\gamma}_t^{x,*} + \hat{\tilde{z}}_t^* \right] + \hat{\mu}_{z,t}. \tag{F.50}$$

Change in real imports

In the data one can observe:

$$\tilde{M}_t \equiv C_t^m + I_t^m, \tag{F.51}$$

Inserting the appropriate demand schedules for C_t^m and I_t^m, one has:

$$\tilde{M}_t \equiv C_t^m + I_t^m = \omega_c \left(\frac{P_t^{m,c}}{P_t^c} \right)^{-\eta_c} C_t + \omega_i \left(\frac{P_t^{m,i}}{P_t^i} \right)^{-\eta_i} I_t. \tag{F.52}$$

Log-linearizing this, gives:

$$\begin{aligned}
\tilde{m}_t &= c_t^m + i_t^m \\
\hat{\tilde{m}}_t &\approx \frac{c^m}{c^m + i^m} \hat{c}_t^m + \frac{i^m}{c^m + i^m} \hat{i}_t^m \\
&= \frac{c^m}{c^m + i^m} \left[-\eta_c (1 - \omega_c) \left(\gamma^{c,d} \right)^{-(1-\eta_c)} \hat{\gamma}_t^{mc,d} + \hat{c}_t \right] \\
&+ \frac{i^m}{c^m + i^m} \left[-\eta_i (1 - \omega_i) \left(\gamma^{i,d} \right)^{-(1-\eta_i)} \hat{\gamma}_t^{mi,d} + \hat{i}_t \right] \\
&= \frac{c^m}{c^m + i^m} \hat{c}_t - \frac{c^m}{c^m + i^m} \eta_c (1 - \omega_c) \left(\gamma^{c,d} \right)^{-(1-\eta_c)} \hat{\gamma}_t^{mc,d} \\
&+ \frac{i^m}{c^m + i^m} \hat{i}_t - \frac{i^m}{c^m + i^m} \eta_i (1 - \omega_i) \left(\gamma^{i,d} \right)^{-(1-\eta_i)} \hat{\gamma}_t^{mi,d}.
\end{aligned} \tag{F.53}$$

The observed real imports ($\tilde{M}_t^{data}$) is assumed to be related to the model's real imports ($\tilde{M}_t$) according to the following expression:

$$\frac{\tilde{M}_t^{data}}{\tilde{M}_{t-1}^{data}} = \frac{\frac{\tilde{M}_t z_t}{z_t}}{\frac{\tilde{M}_{t-1} z_{t-1}}{z_{t-1}}}. \tag{F.54}$$

Taking logarithms, gives:

$$\ln \tilde{M}_t^{data} - \ln \tilde{M}_{t-1}^{data} = \ln \tilde{m}_t - \ln \tilde{m}_{t-1} + \ln \mu_{z,t}. \tag{F.55}$$

Adding and substracting $\ln \tilde{m}$ and $\ln \mu_z$ from the right hand side of the above equation, gives:

$$\ln \tilde{M}_t^{data} - \ln \tilde{M}_{t-1}^{data} = \ln \tilde{m}_t - \ln \tilde{m} - (\ln \tilde{m}_{t-1} - \ln \tilde{m}) + \ln \mu_{z,t} - \ln \mu_z + \ln \mu_z, \tag{F.56}$$

which can be further rewritten as follows:

$$\ln \tilde{M}_t^{data} - \ln \tilde{M}_{t-1}^{data} = \ln \mu_z + \hat{\tilde{m}}_t - \hat{\tilde{m}}_{t-1} + \hat{\mu}_{z,t}. \tag{F.57}$$

Using (F.53) in the above expression, yields:

$$\begin{aligned} \Delta \ln \tilde{M}_t^{data} = &\ln \mu_z + \frac{c^m}{c^m + i^m} \Delta \hat{c}_t - \frac{c^m}{c^m + i^m} \eta_c \left(1 - \omega_c\right) \left(\gamma^{c,d}\right)^{-(1-\eta_c)} \Delta \hat{\gamma}_t^{mc,d} \\ &+ \frac{i^m}{c^m + i^m} \Delta \hat{i}_t - \frac{i^m}{c^m + i^m} \eta_i \left(1 - \omega_i\right) \left(\gamma^{i,d}\right)^{-(1-\eta_i)} \Delta \hat{\gamma}_t^{mi,d} + \hat{\mu}_{z,t}. \end{aligned} \tag{F.58}$$

Change in real government consumption

The observed government consumption (G_t^{data}) is assumed to be related to the model's government consumption (G_t) according to the following expression:

$$\frac{G_t^{data}}{G_{t-1}^{data}} = \frac{\frac{G_t z_t}{z_t}}{\frac{G_{t-1} z_{t-1}}{z_{t-1}}}. \tag{F.59}$$

Taking logarithms, gives:

$$\ln G_t^{data} - \ln G_{t-1}^{data} = \ln g_t - \ln g_{t-1} + \ln \mu_{z,t}. \tag{F.60}$$

Adding and substracting $\ln g$ and $\ln \mu_z$ from the right hand side of the above equation, it can be obtained:

$$\ln G_t^{data} - \ln G_{t-1}^{data} = \ln g_t - \ln g - (\ln g_{t-1} - \ln g) + \ln \mu_{z,t} - \ln \mu_z + \ln \mu_z, \tag{F.61}$$

which can be further rewritten as follows:

$$\ln G_t^{data} - \ln G_{t-1}^{data} = \ln \mu_z + \hat{g}_t - \hat{g}_{t-1} + \hat{\mu}_{z,t} \tag{F.62}$$

or:

$$\Delta \ln G_t^{data} = \ln \mu_z + \Delta \hat{g}_t + \hat{\mu}_{z,t}. \tag{F.63}$$

Foreign output (GDP)

The observed foreign GDP ($Y_t^{*,data}$) is assumed to be related to the model's foreign GDP (Y_t^*) according to the following expression:

$$\frac{Y_t^{*,data}}{Y_{t-1}^{*,data}} = \frac{\frac{Y_t^* z_t^* z_t}{z_t^* z_t}}{\frac{Y_{t-1}^* z_{t-1}^* z_{t-1}}{z_{t-1}^* z_{t-1}}}. \tag{F.64}$$

Taking logarithms, yields:

$$\ln Y_t^{*,data} - \ln Y_{t-1}^{*,data} = \ln y_t^* - \ln y_{t-1}^* + \ln \tilde{z}_t^* - \ln \tilde{z}_{t-1}^* + \ln \mu_{z,t}. \tag{F.65}$$

Adding and substracting $\ln y^*$, $\ln \tilde{z}^*$ and $\ln \mu_z$ from the right hand side of the above equation, it can be obtained:

$$\begin{aligned} \ln Y_t^{*,data} - \ln Y_{t-1}^{*,data} &= \ln y_t^* - \ln y^* - \left(\ln y_{t-1}^* - \ln y^*\right) + \ln \tilde{z}_t^* - \ln \tilde{z}^* \\ &\quad - \left(\ln \tilde{z}_{t-1}^* - \ln \tilde{z}^*\right) + \ln \mu_{z,t} - \ln \mu_z + \ln \mu_z, \end{aligned} \tag{F.66}$$

which can be further rewritten as follows:

$$\ln Y_t^{*,data} - \ln Y_{t-1}^{*,data} = \ln \mu_z + \hat{y}_t^* - \hat{y}_{t-1}^* + \hat{\tilde{z}}_t^* - \hat{\tilde{z}}_{t-1}^* + \hat{\mu}_{z,t} \tag{F.67}$$

or:

$$\Delta \ln Y_t^{*,data} = \ln \mu_z + \Delta \hat{y}_t^* + \Delta \hat{\tilde{z}}_t^* + \hat{\mu}_{z,t}. \tag{F.68}$$

Foreign inflation

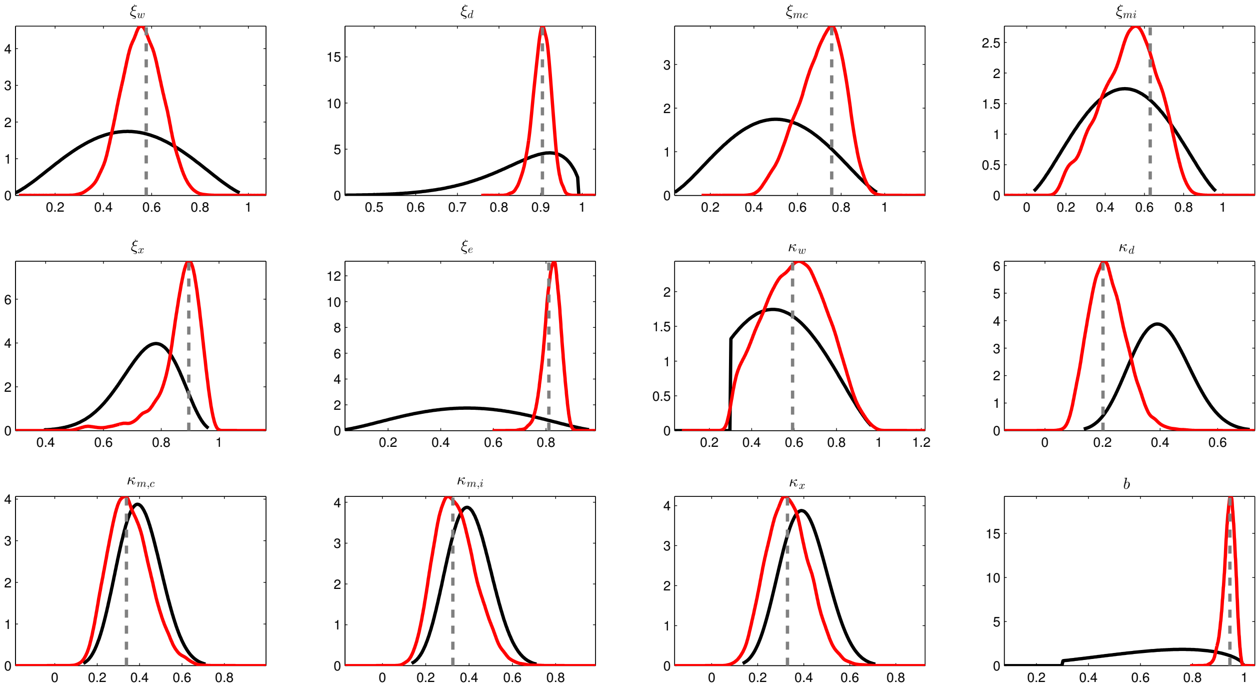
$$\pi_t^{*,data} = (\pi - 1) + \hat{\pi}_t^* \tag{F.69}$$

Foreign interest rate

$$R_t^{*,data} = 4\,(R-1) + 4R\hat{R}_t^* \tag{F.70}$$

Appendix G. Prior and posterior distributions

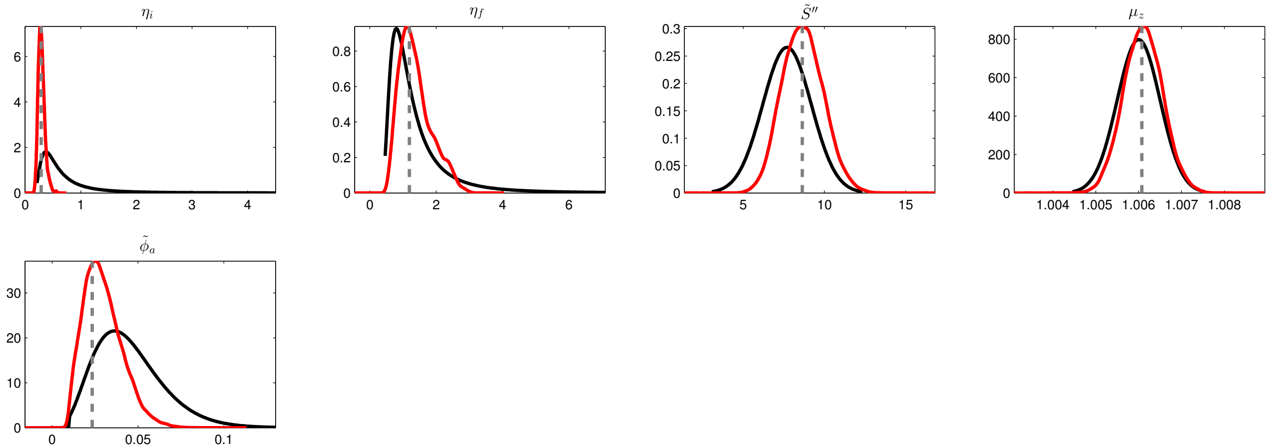
Figure G.1a: *Prior and posterior distributions of the structural parameters, friction parameters*



Notes: Prior (black) vs. posterior (red) distributions for the estimated structural parameters. The gray dashed vertical line is the posterior mode obtained from the posterior kernel maximization. Estimates obtained from Bayesian estimation of the DSGE model using Slovenian macroeconomic data from 1995Q1-2014Q4.

Source: Own work.

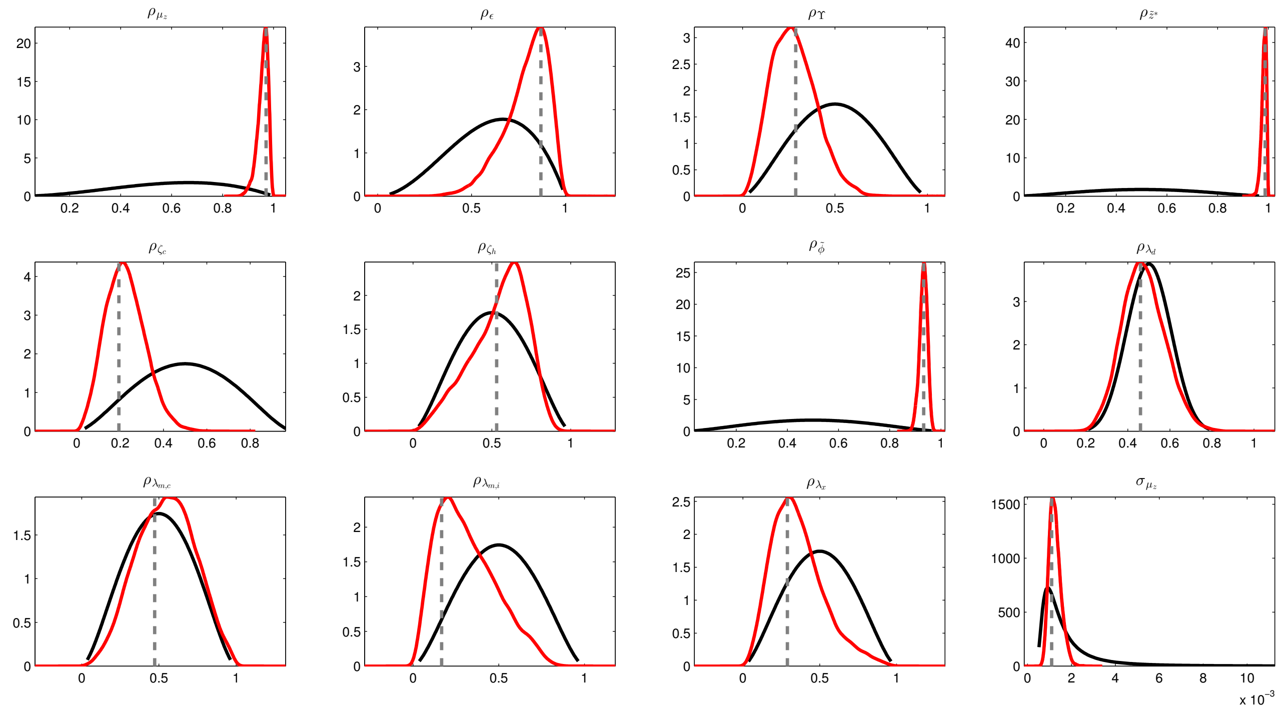
Figure G.1b: *Prior and posterior distributions of the structural parameters, friction parameters (cont.)*



Notes: Prior (black) vs. posterior (red) distributions for the estimated structural parameters. The gray dashed vertical line is the posterior mode obtained from the posterior kernel maximization. Estimates obtained from Bayesian estimation of the DSGE model using Slovenian macroeconomic data from 1995Q1-2014Q4.

Source: Own work.

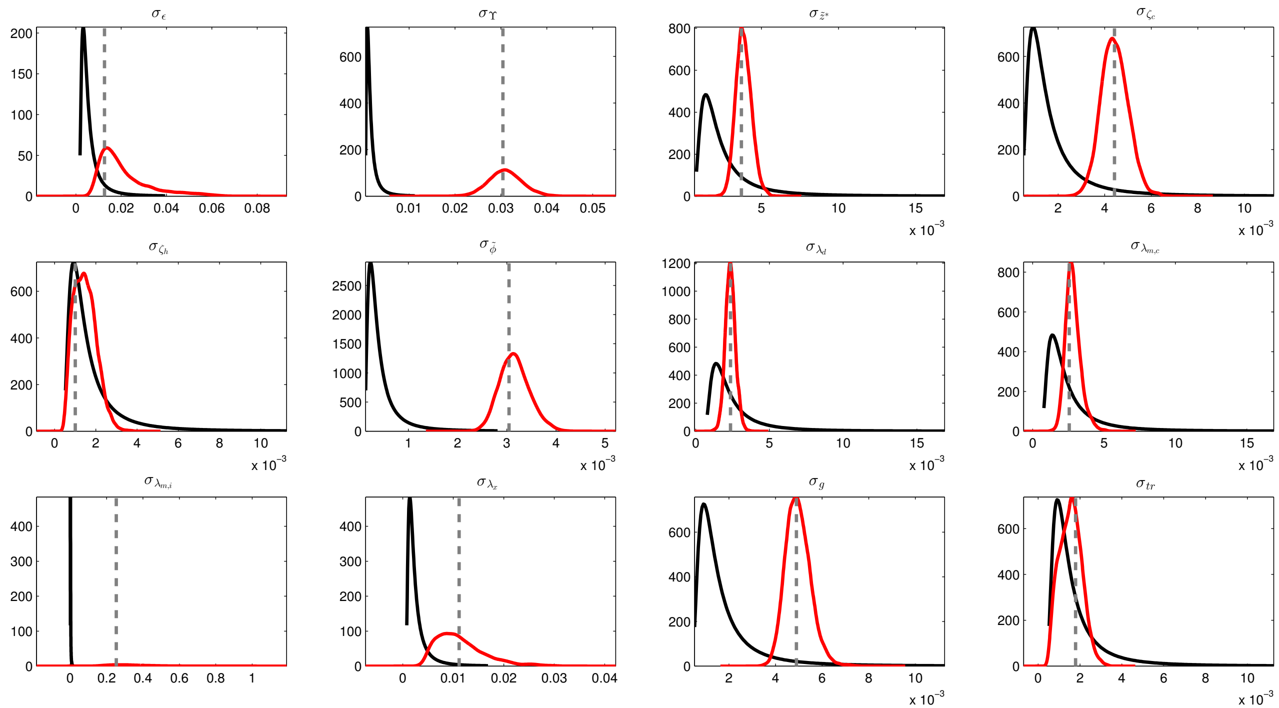
Figure G.1c: *Prior and posterior distributions of the structural parameters, shock processes parameters*



Notes: Prior (black) vs. posterior (red) distributions for the estimated structural parameters. The gray dashed vertical line is the posterior mode obtained from the posterior kernel maximization. Estimates obtained from Bayesian estimation of the DSGE model using Slovenian macroeconomic data from 1995Q1-2014Q4.

Source: Own work.

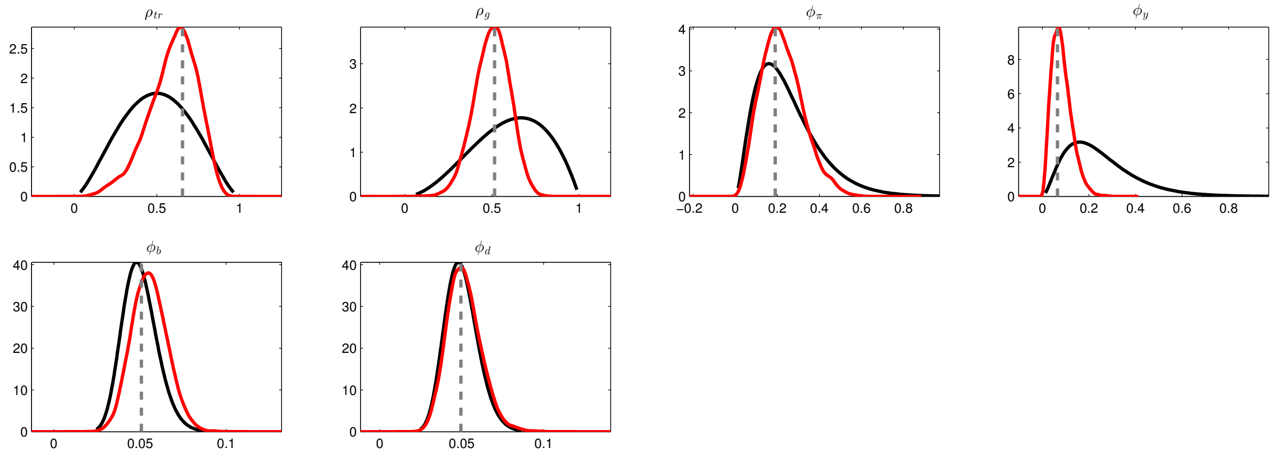
Figure G.1d: *Prior and posterior distributions of the structural parameters, shock processes parameters (cont.)*



Notes: Prior (black) vs. posterior (red) distributions for the estimated structural parameters. The gray dashed vertical line is the posterior mode obtained from the posterior kernel maximization. Estimates obtained from Bayesian estimation of the DSGE model using Slovenian macroeconomic data from 1995Q1-2014Q4.

Source: Own work.

Figure G.1e: *Prior and posterior distributions of the structural parameters, policy parameters*

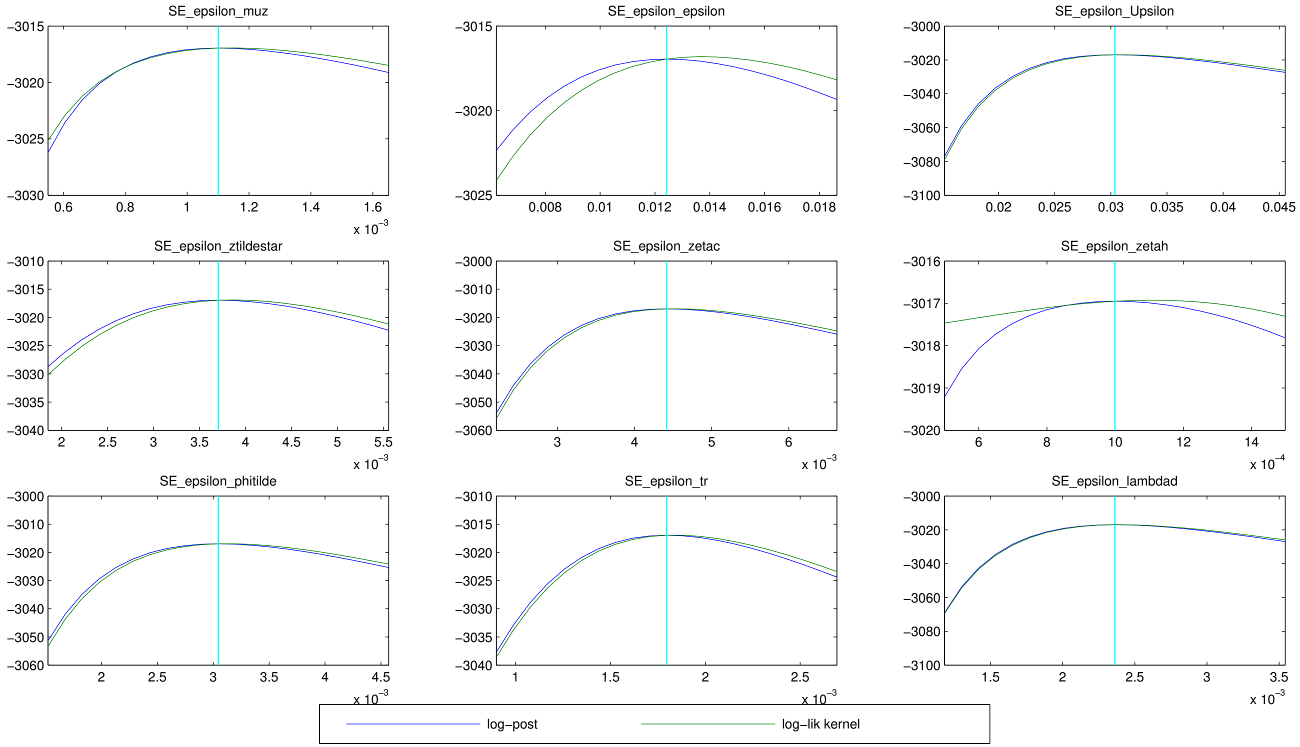


Notes: Prior (black) vs. posterior (red) distributions for the estimated structural parameters. The gray dashed vertical line is the posterior mode obtained from the posterior kernel maximization. Estimates obtained from Bayesian estimation of the DSGE model using Slovenian macroeconomic data from 1995Q1-2014Q4.

Source: Own work.

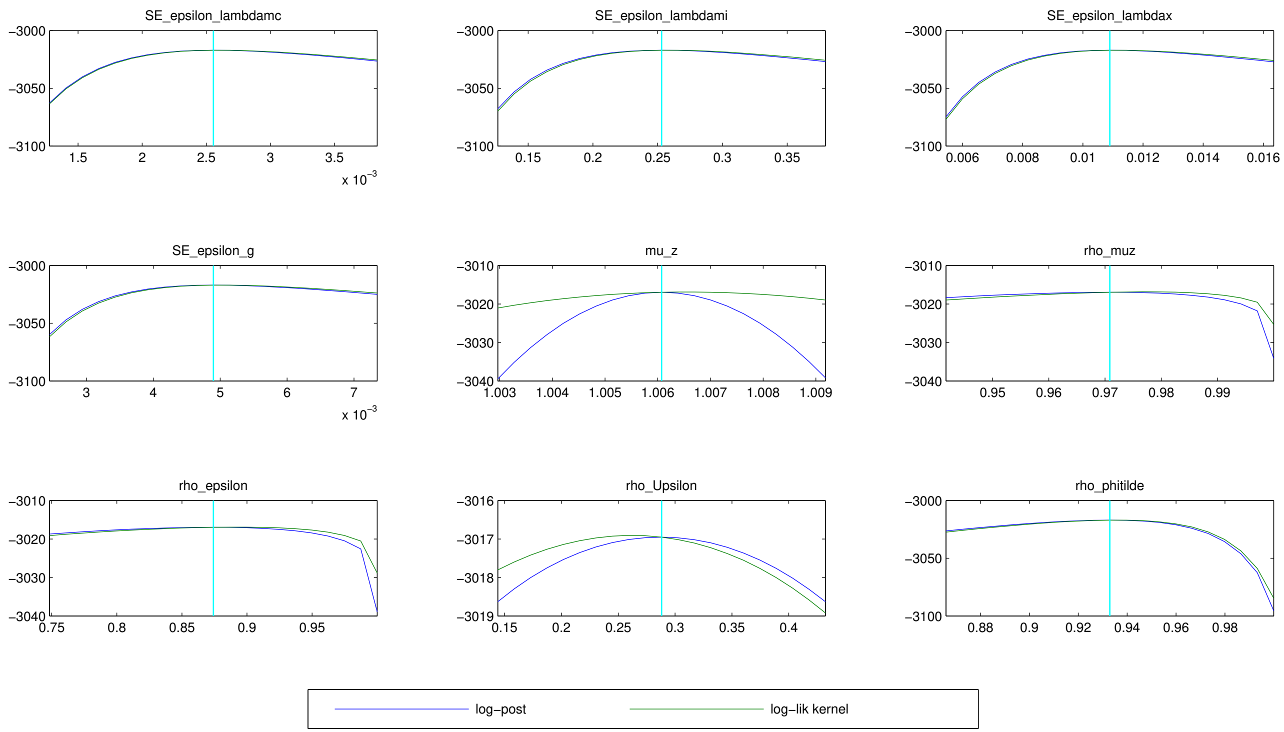
Appendix H. Diagnostic plots

Figure H.1a: *Check plots for posterior mode maximization*



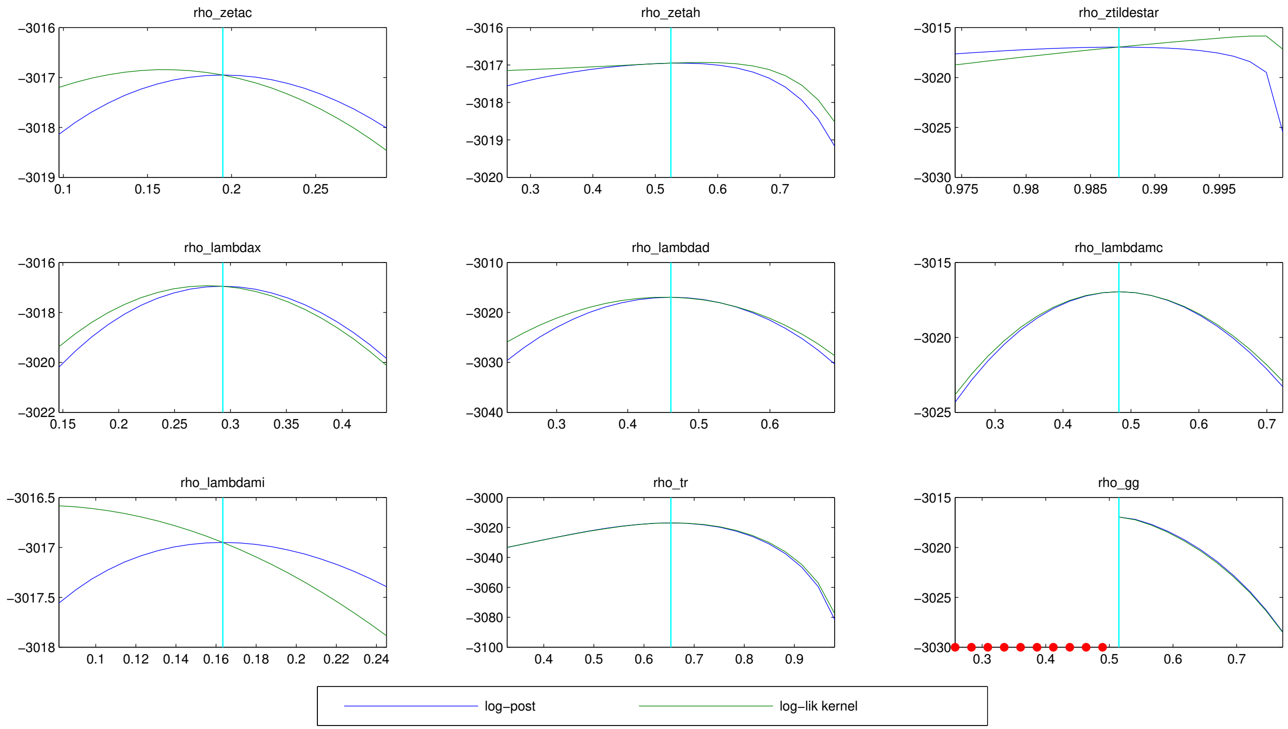
Source: Own work.

Figure H.1b: *Check plots for posterior mode maximization (cont.)*



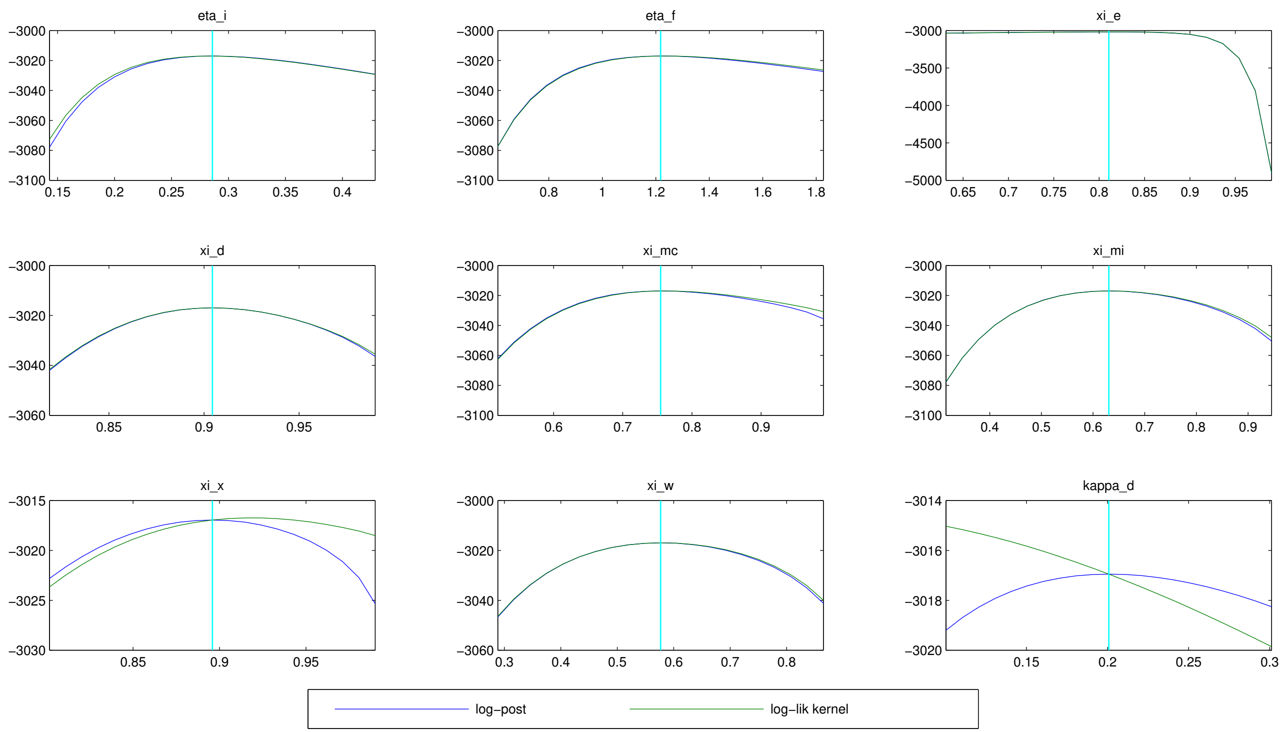
Source: Own work.

Figure H.1c: *Check plots for posterior mode maximization (cont.)*



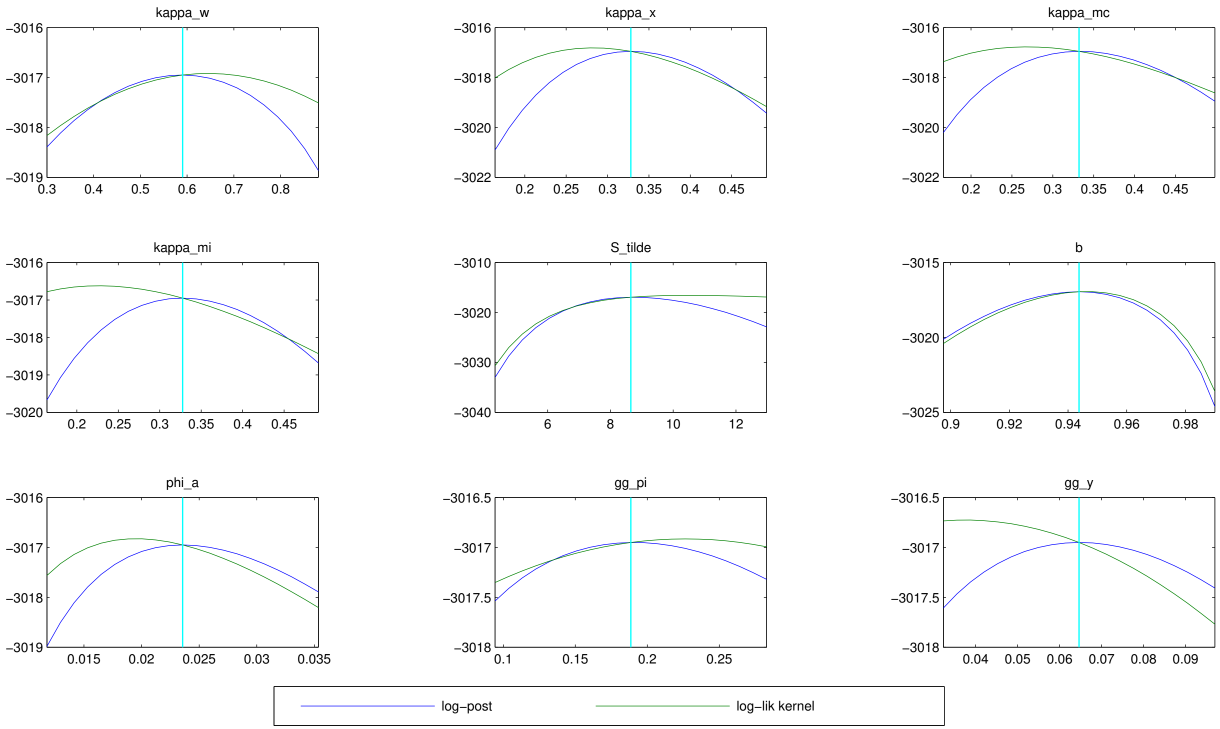
Source: Own work.

Figure H.1d: *Check plots for posterior mode maximization (cont.)*



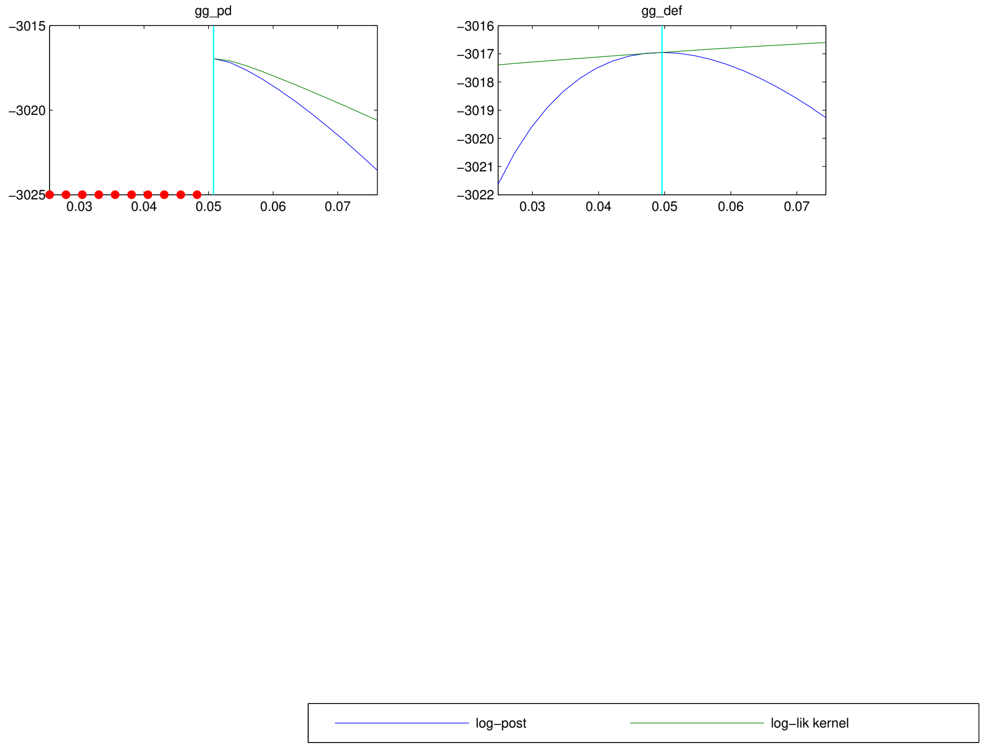
Source: Own work.

Figure H.1e: *Check plots for posterior mode maximization (cont.)*



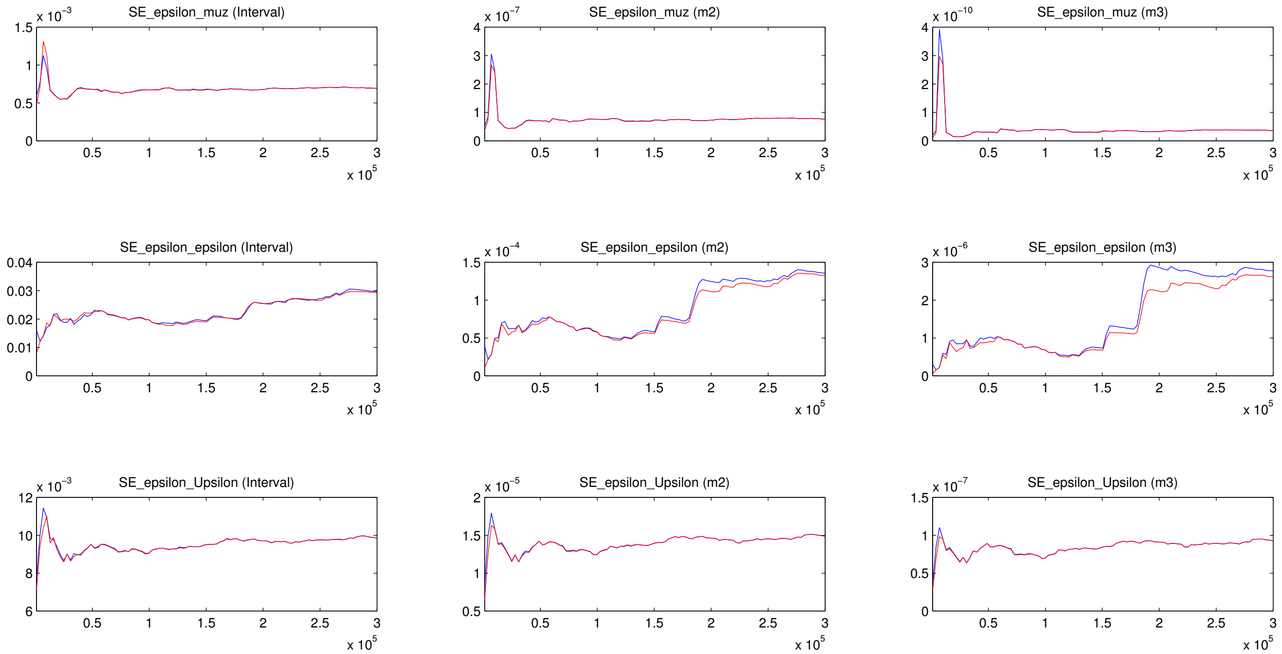
Source: Own work.

Figure H.1f: *Check plots for posterior mode maximization (cont.)*



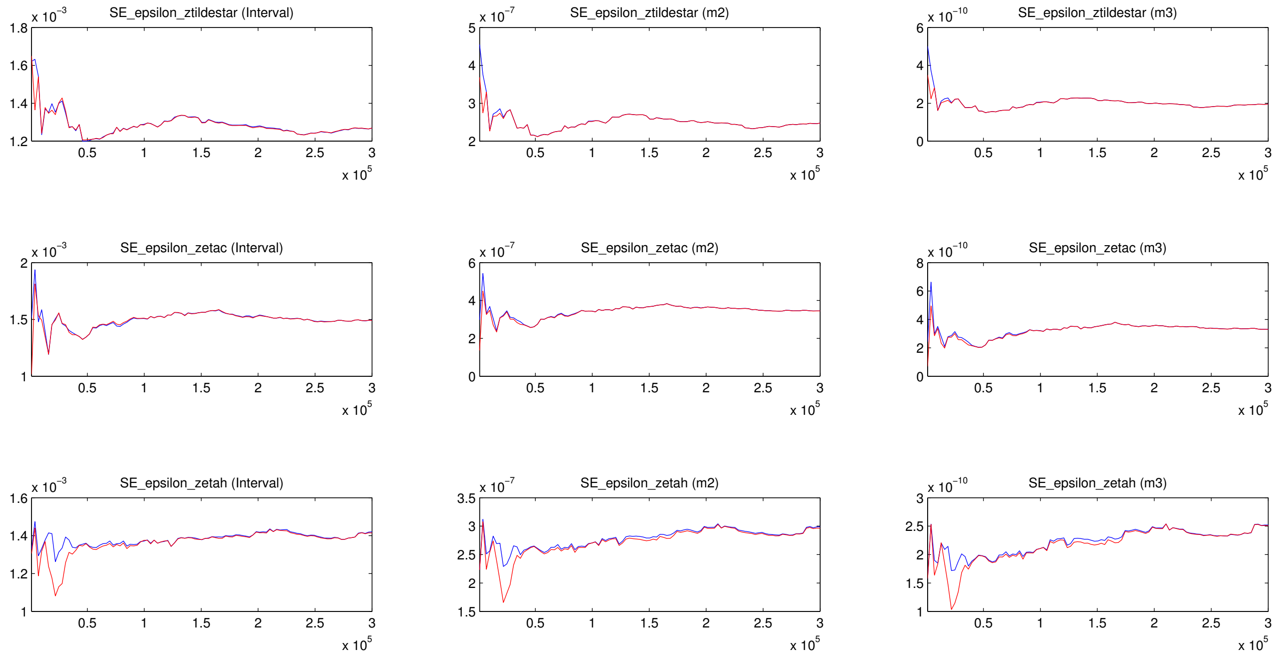
Source: Own work.

Figure H.2a: *MCMC univariate diagnostic (Brooks and Gelman, 1998)*



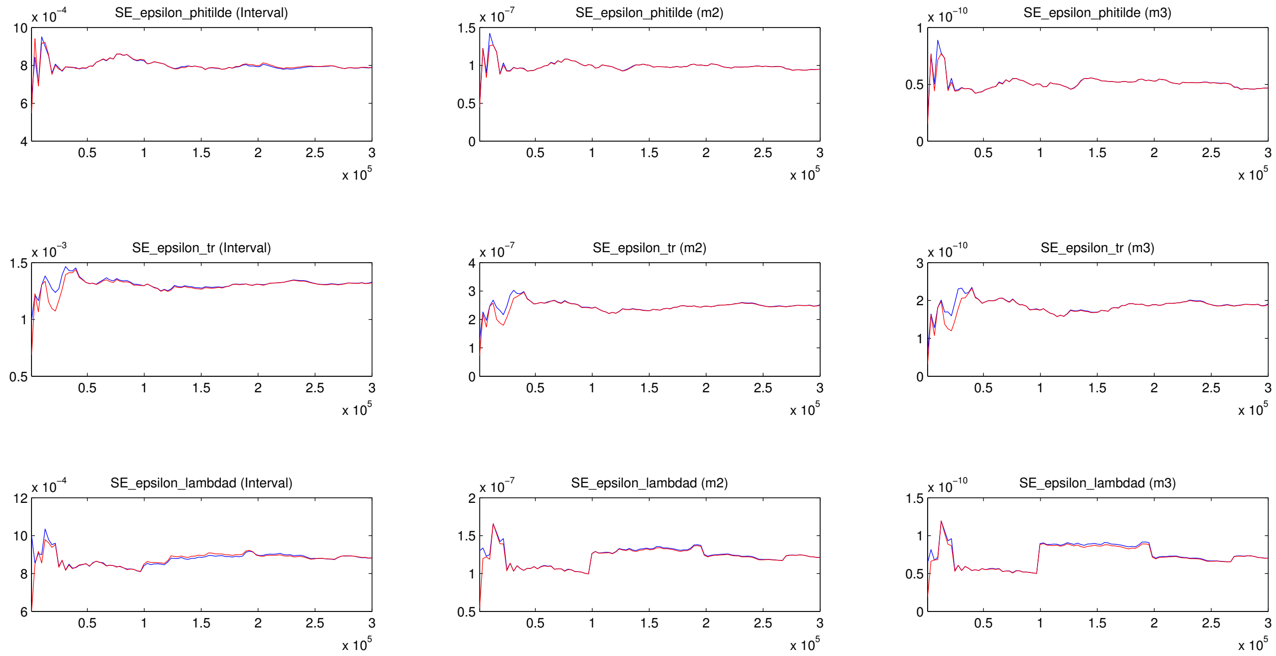
Source: Own work.

Figure H.2b: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



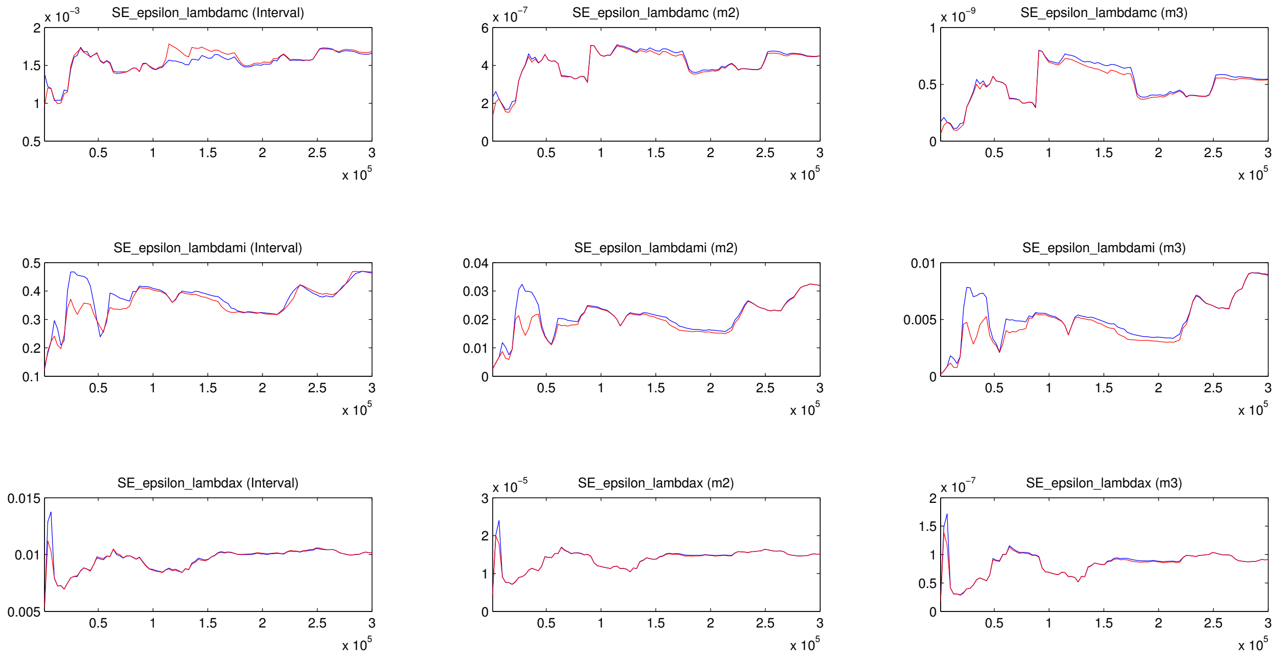
Source: Own work.

Figure H.2c: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



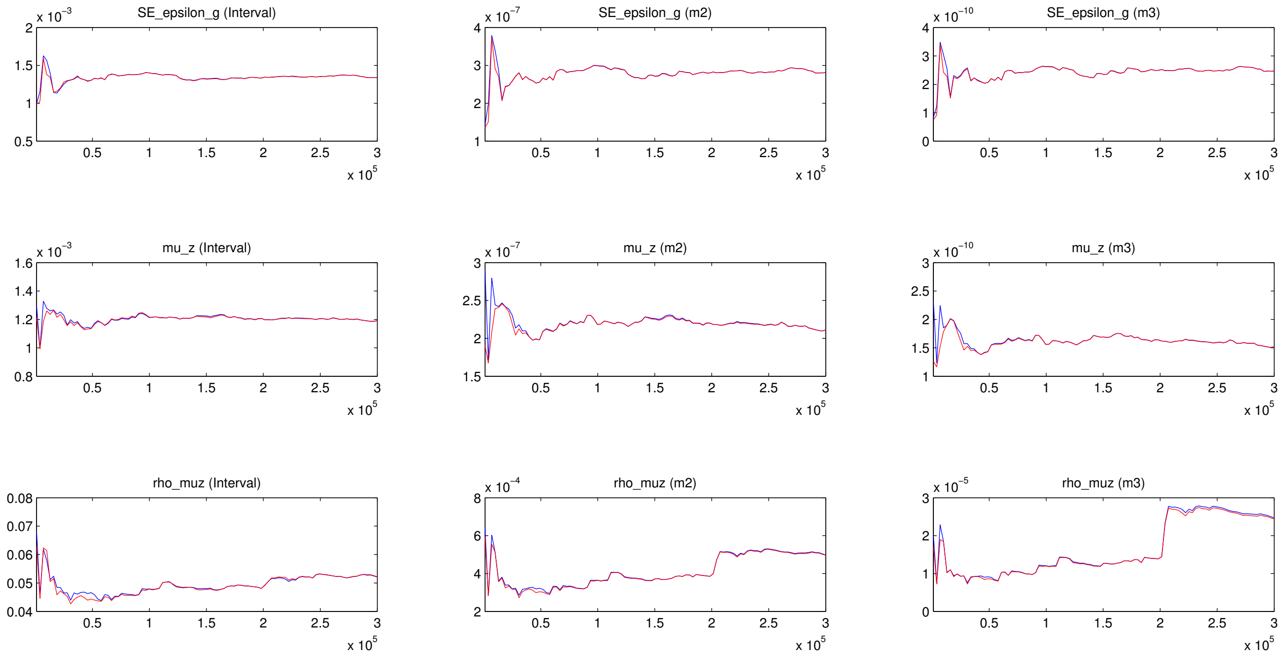
Source: Own work.

Figure H.2d: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



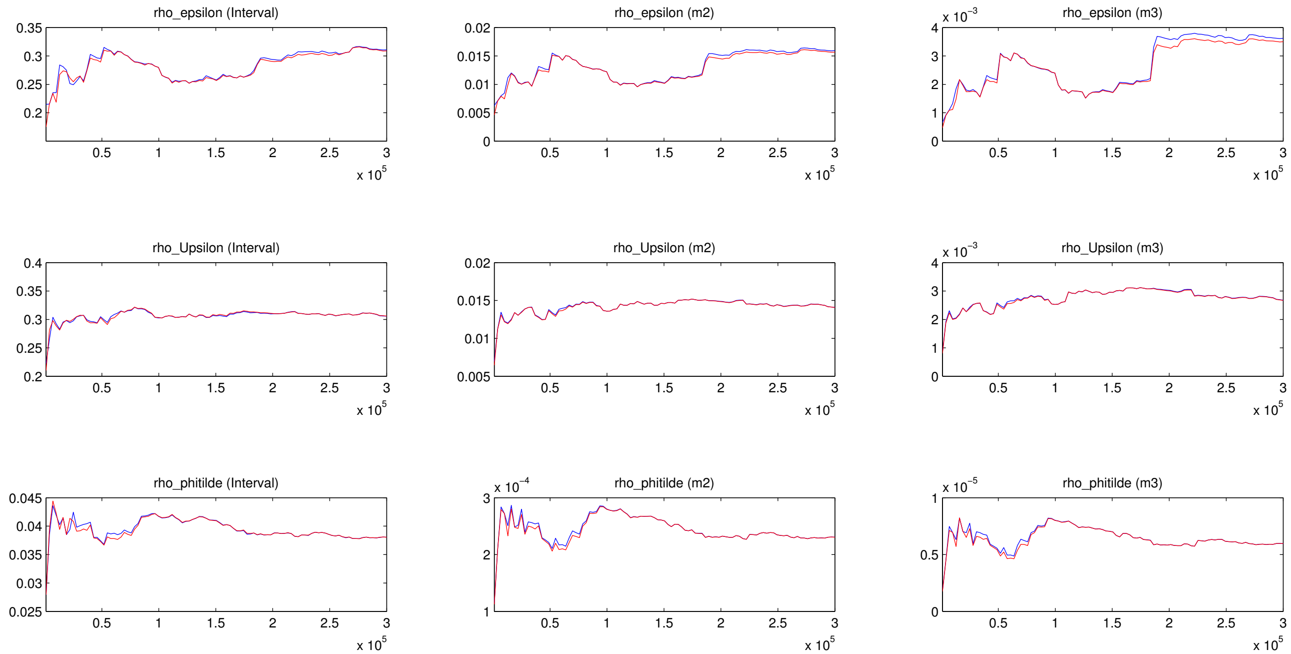
Source: Own work.

Figure H.2e: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



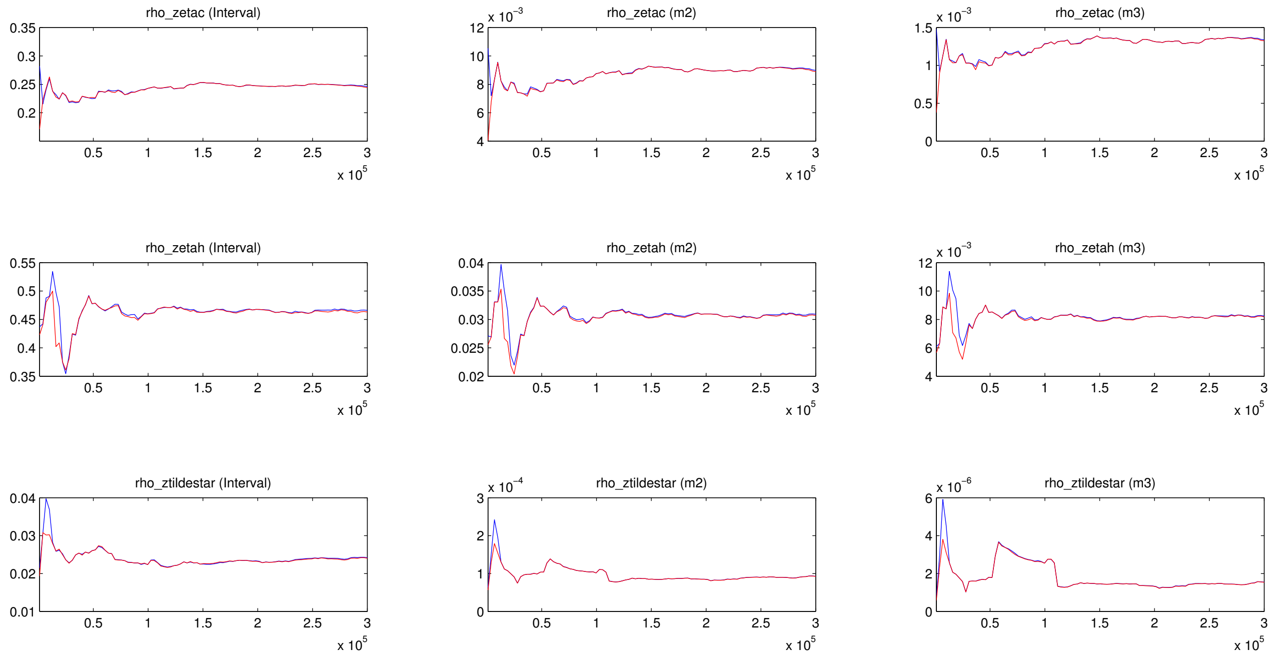
Source: Own work.

Figure H.2f: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



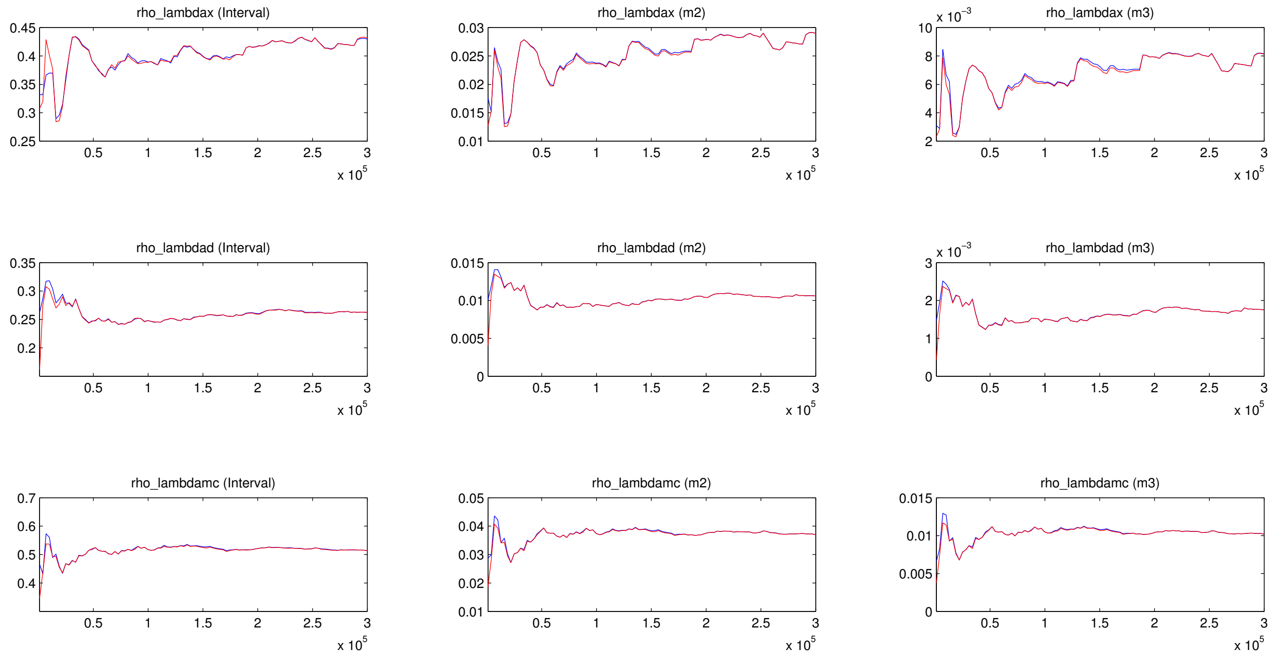
Source: Own work.

Figure H.2g: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



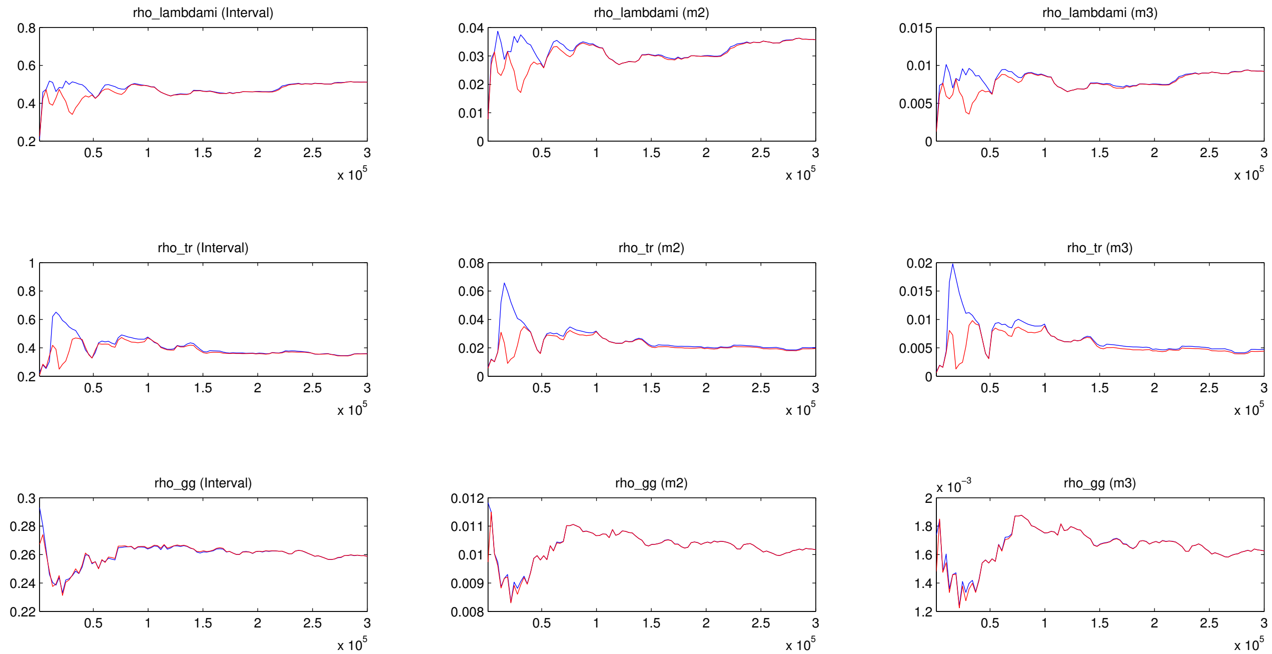
Source: Own work.

Figure H.2h: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



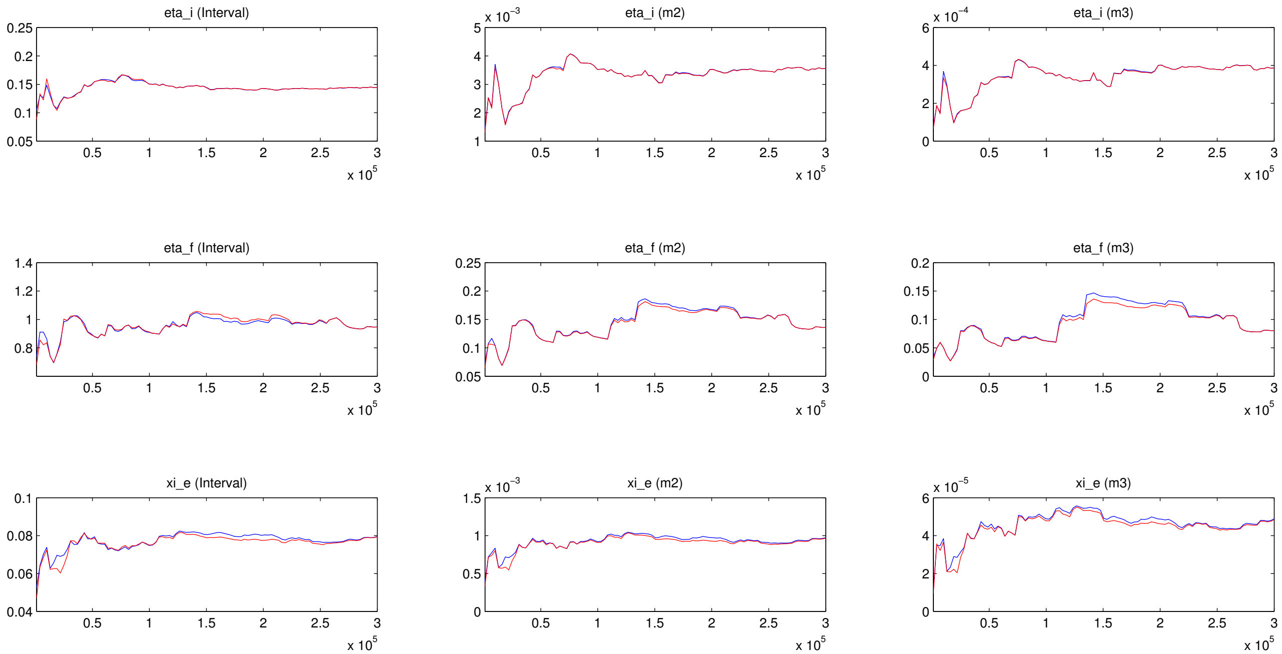
Source: Own work.

Figure H.2i: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



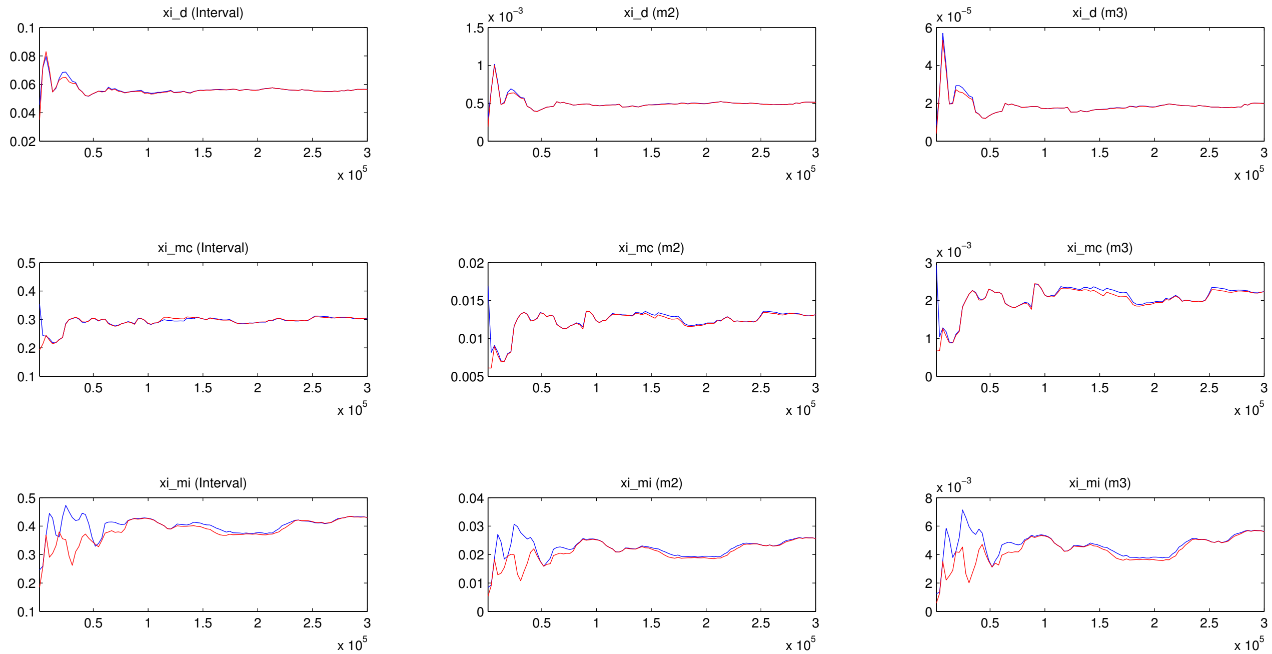
Source: Own work.

Figure H.2j: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



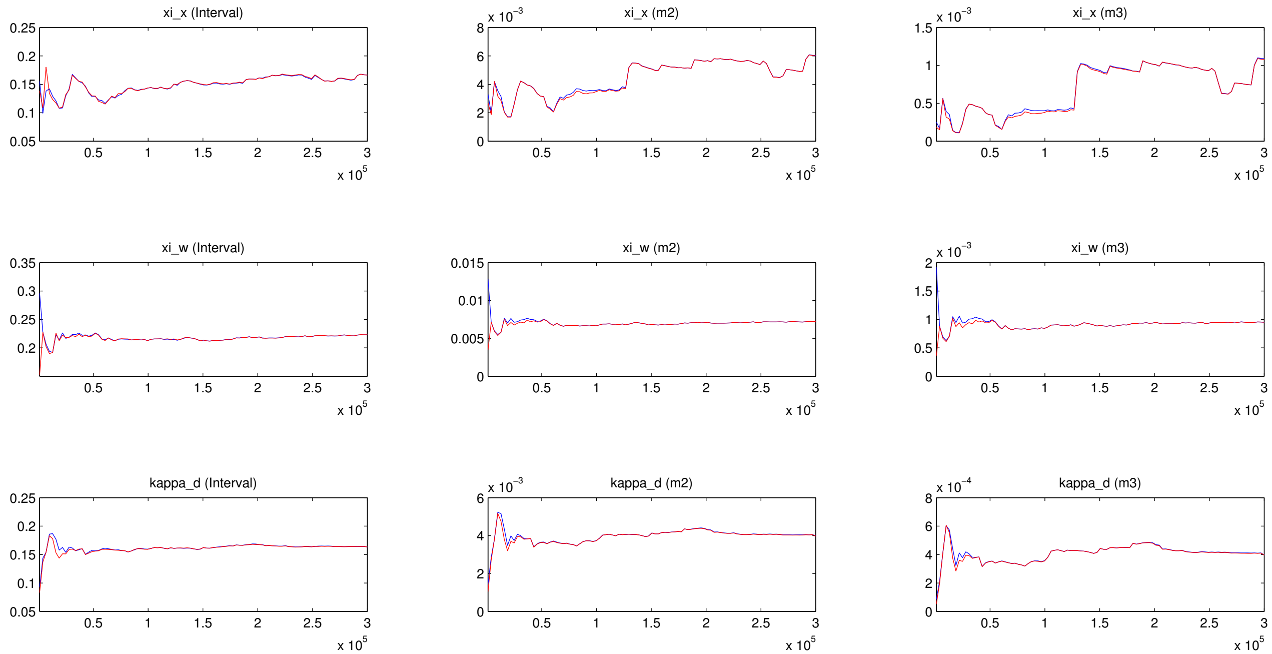
Source: Own work.

Figure H.2k: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



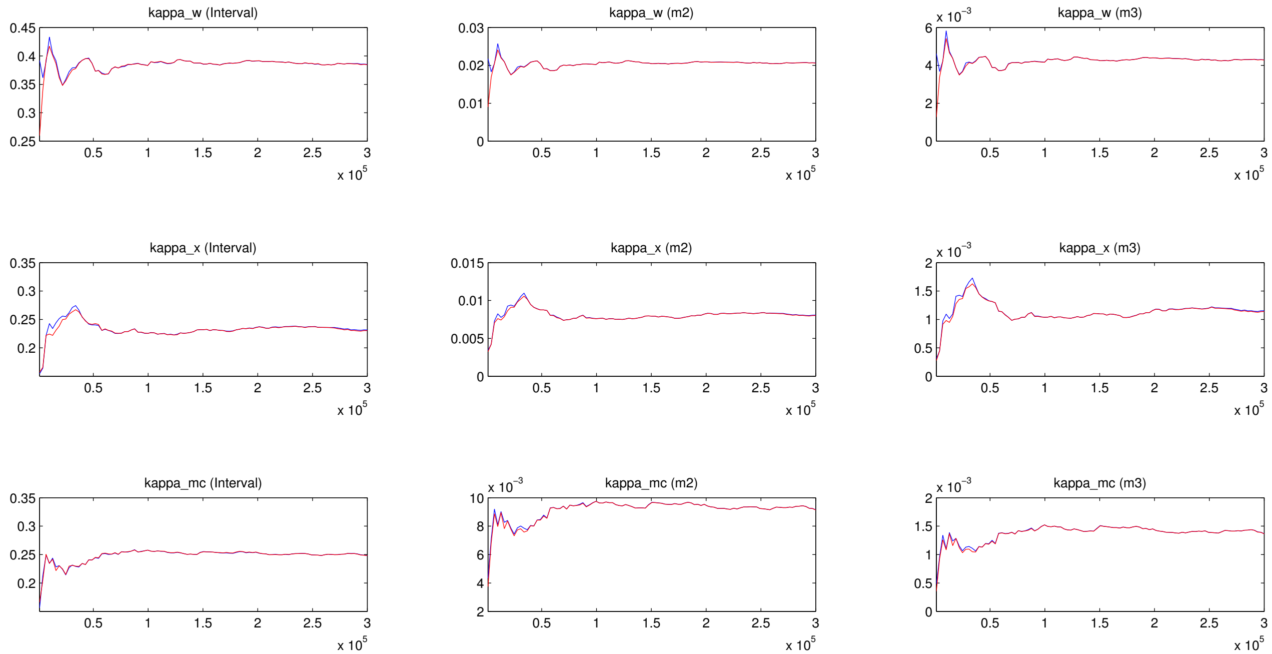
Source: Own work.

Figure H.2l: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



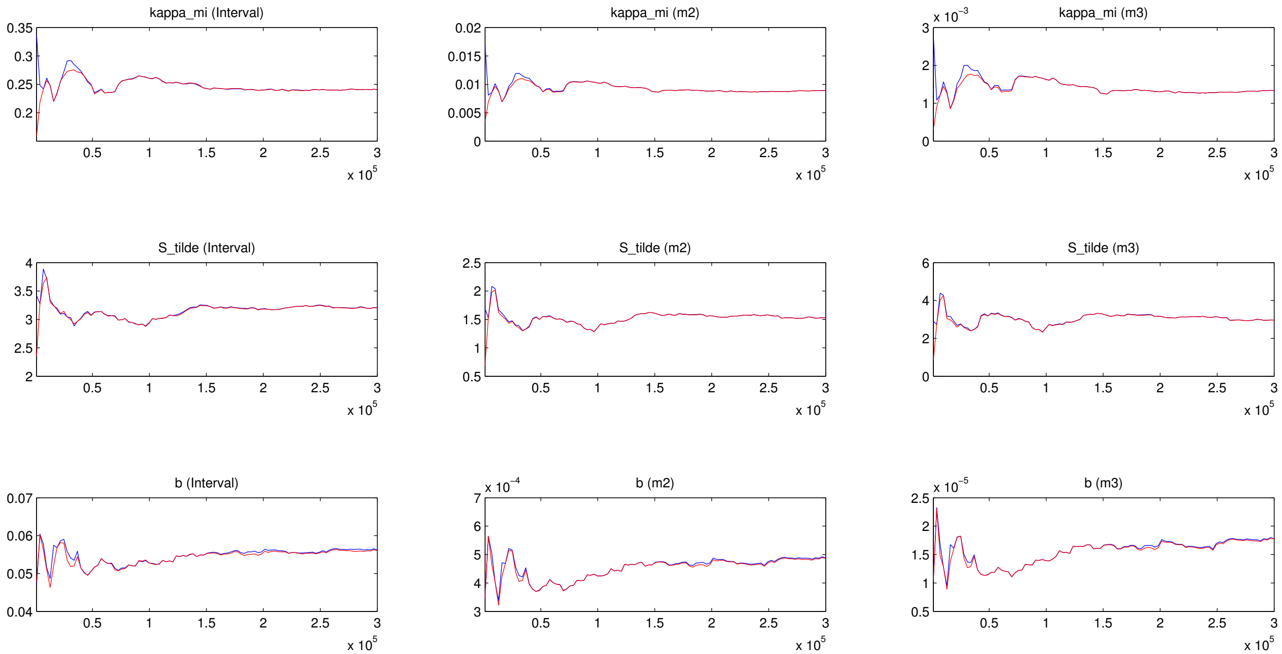
Source: Own work.

Figure H.2m: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



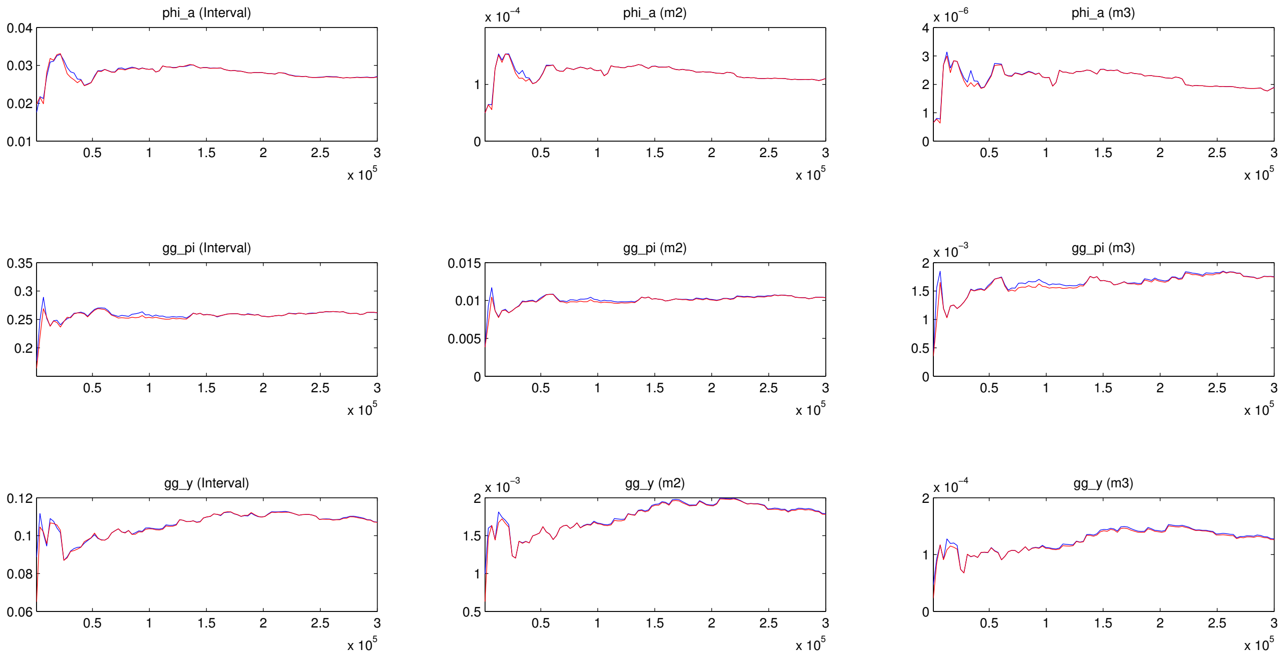
Source: Own work.

Figure H.2n: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



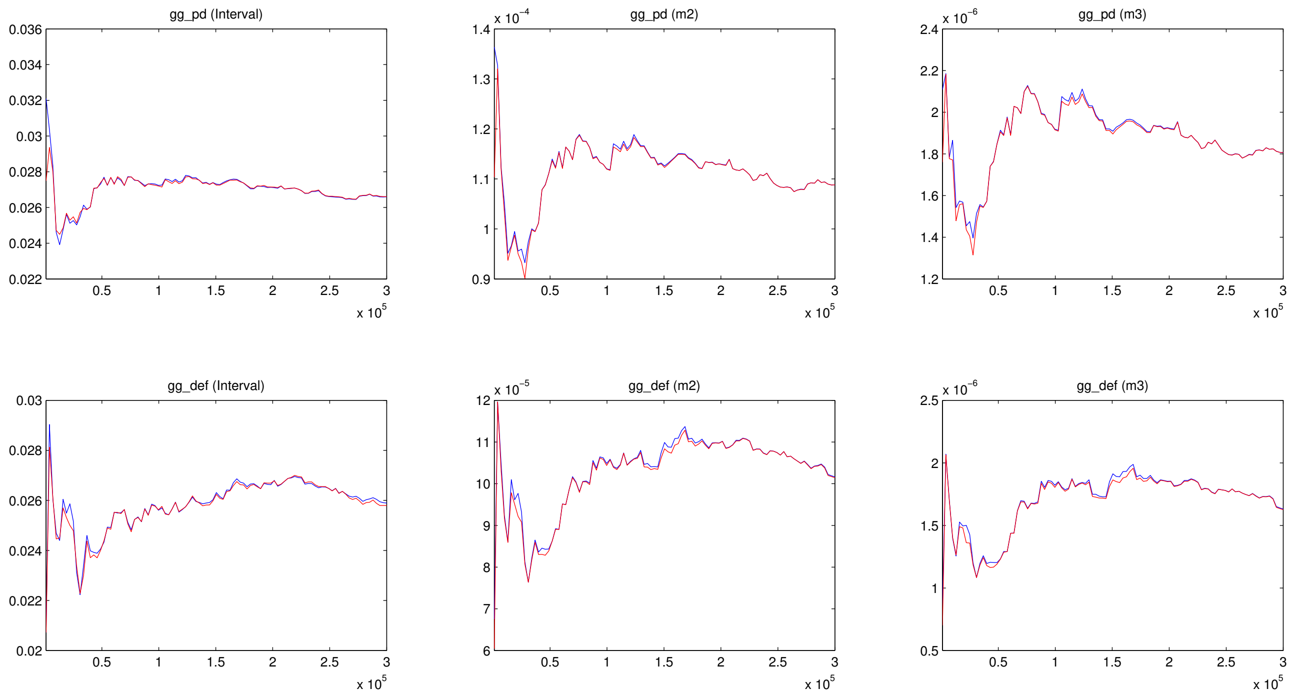
Source: Own work.

Figure H.2o: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



Source: Own work.

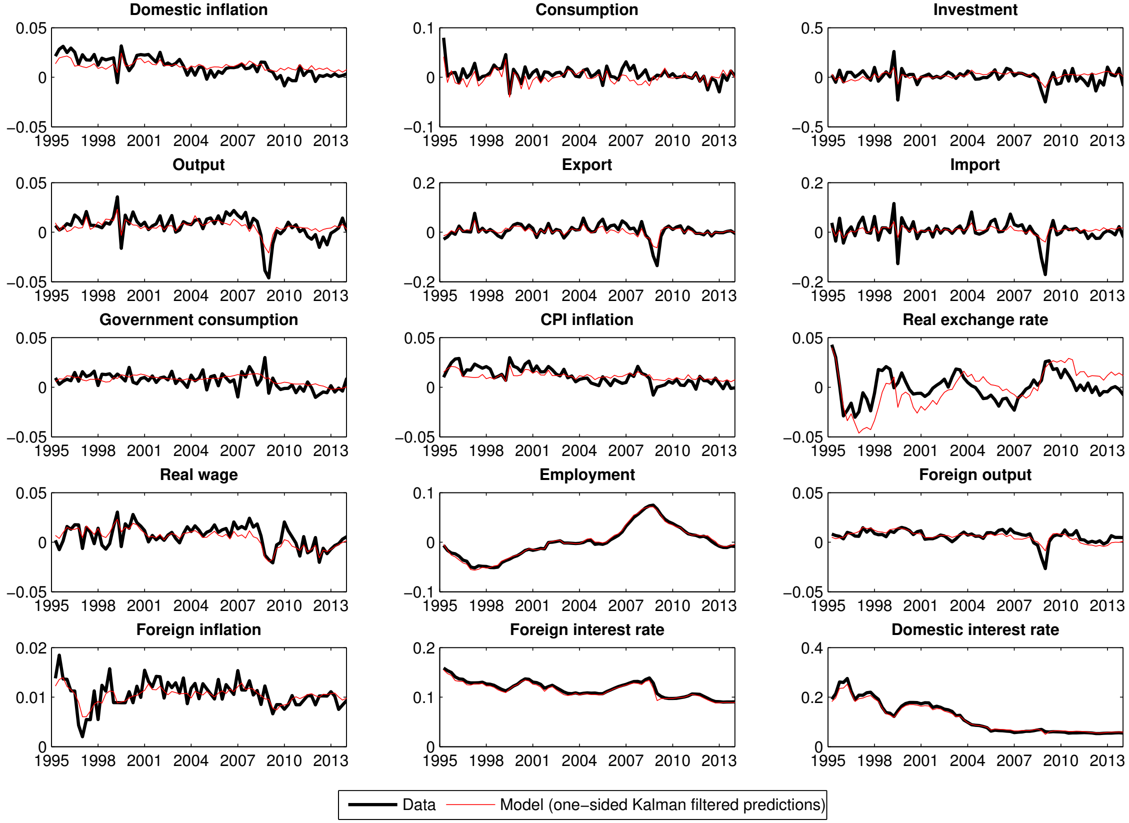
Figure H.2p: *MCMC univariate diagnostic (Brooks and Gelman, 1998) (cont.)*



Source: Own work.

Appendix I. Data and one-sided predicted values from the model

Figure I.1: *Data (thick black) and one-sided Kalman-filtered predictions (thin red)*

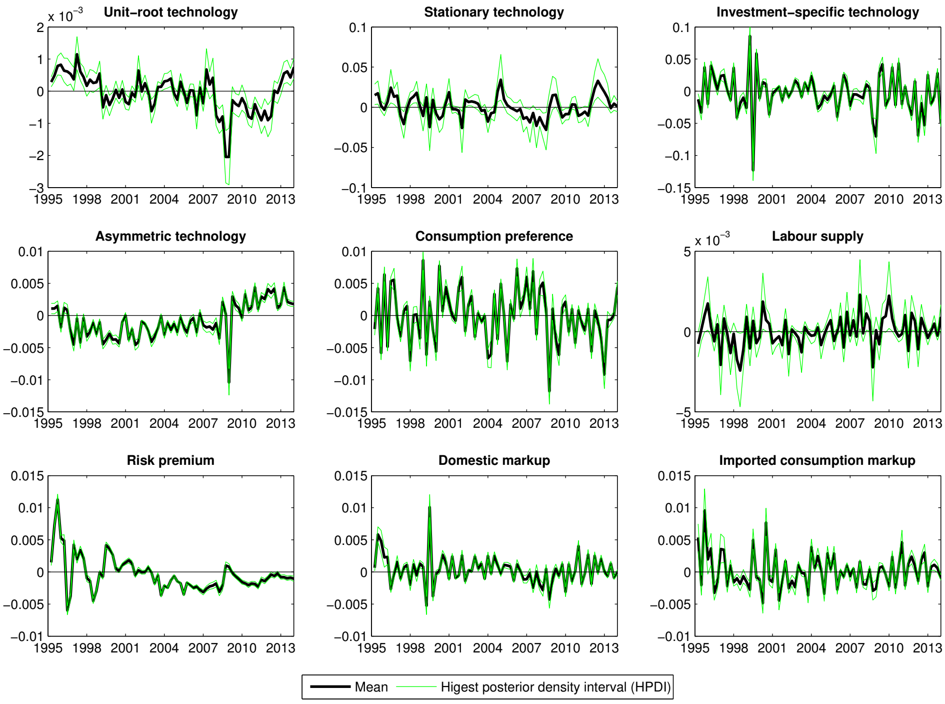


Notes: The plot shows deviations from steady state/trend.

Source: Own work.

Appendix J. Smoothed shocks

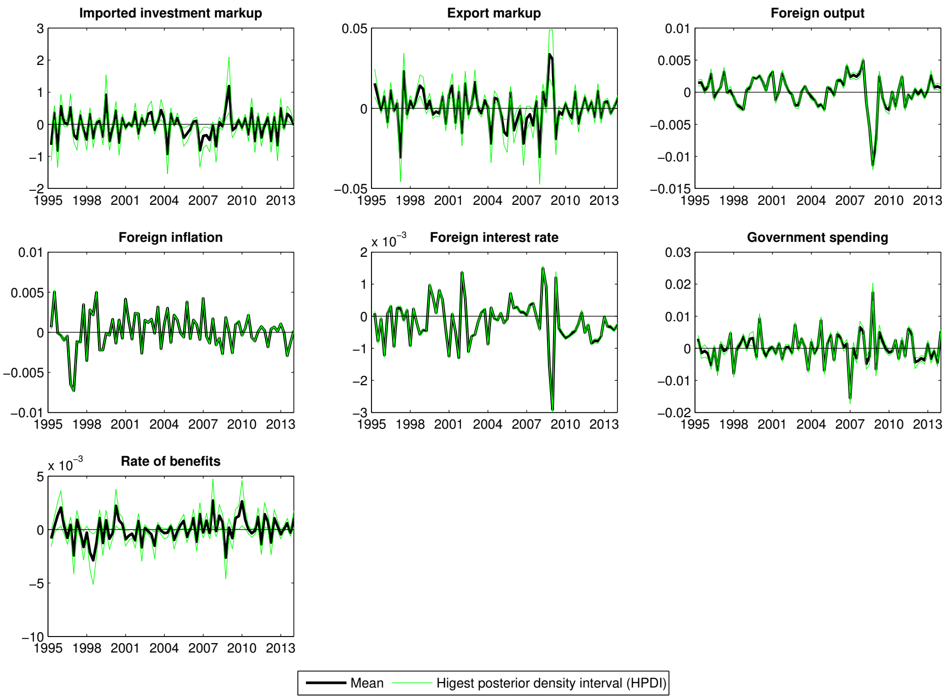
Figure J.1a: *Smoothed (two-sided Kalman filtered) estimates of the structural shocks (deviations from steady state)*



Notes: The plot shows deviations from steady state.

Source: Own work.

Figure J.1b: *Smoothed (two-sided Kalman filtered) estimates of the structural shocks (deviations from steady state) (cont.)*

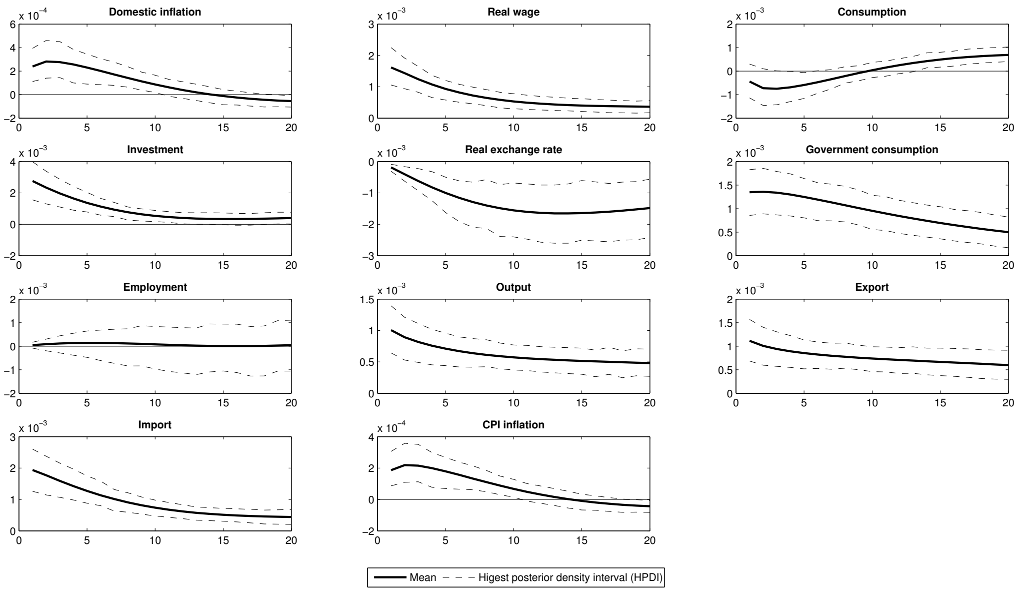


Notes: The plot shows deviations from steady state.

Source: Own work.

Appendix K. Impulse response functions

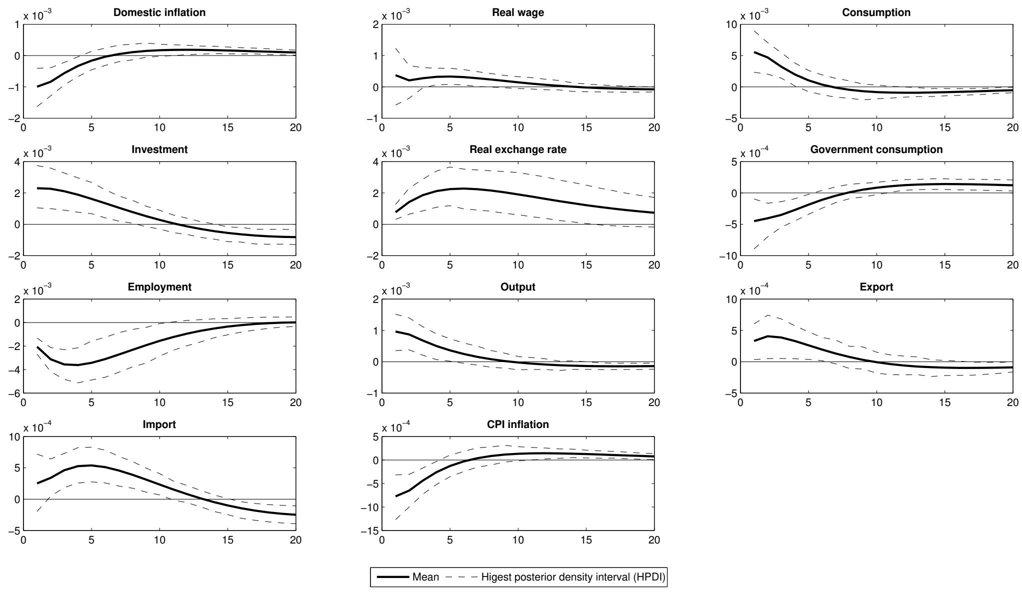
Figure K.1: *Impulse responses to a unit-root technology shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

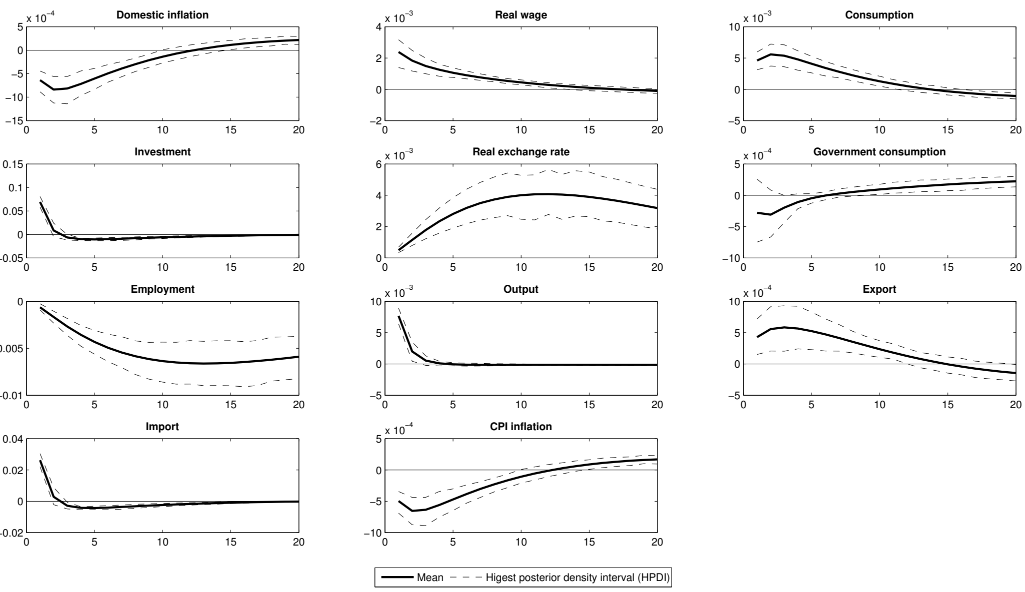
Figure K.2: *Impulse responses to a stationary technology shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

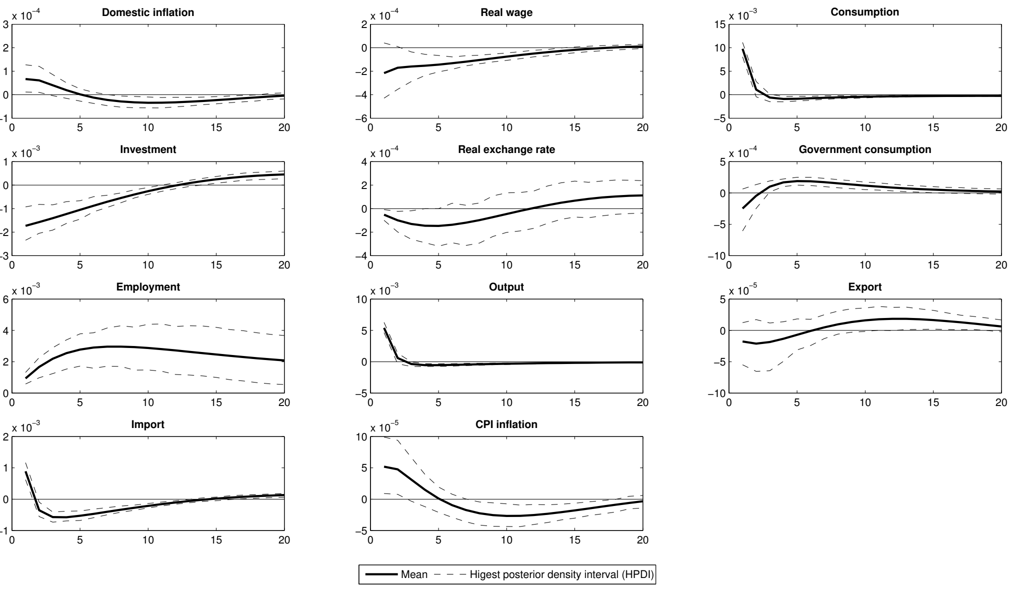
Figure K.3: *Impulse responses to an investment-specific technology shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

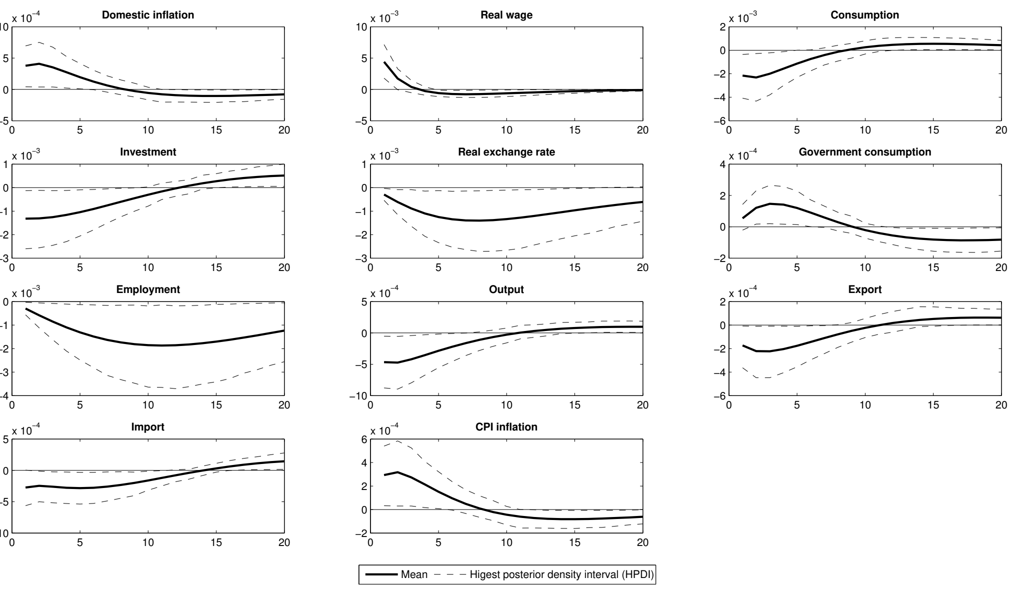
Figure K.4: *Impulse responses to a consumption preference shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

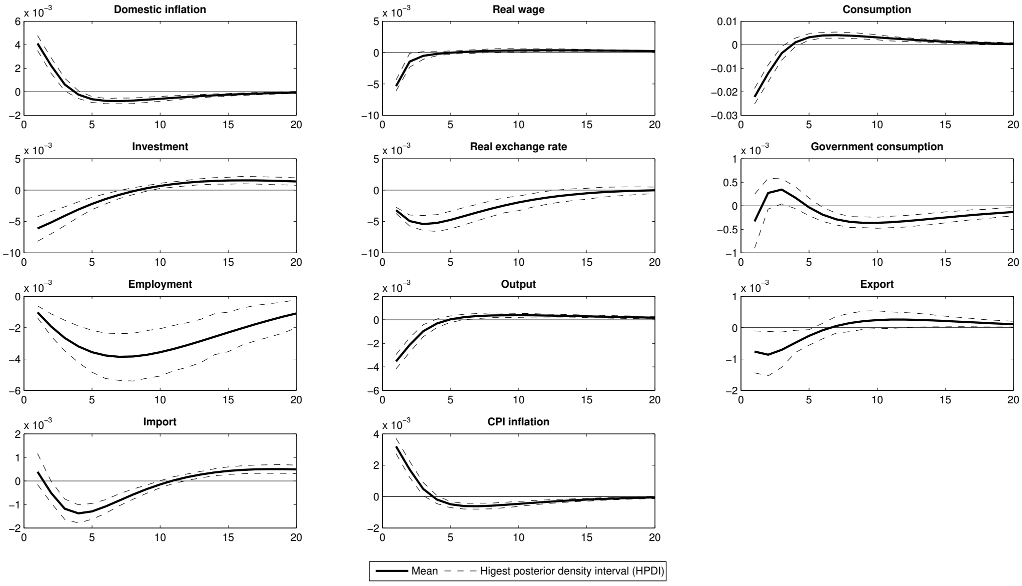
Figure K.5: *Impulse responses to a labour supply shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

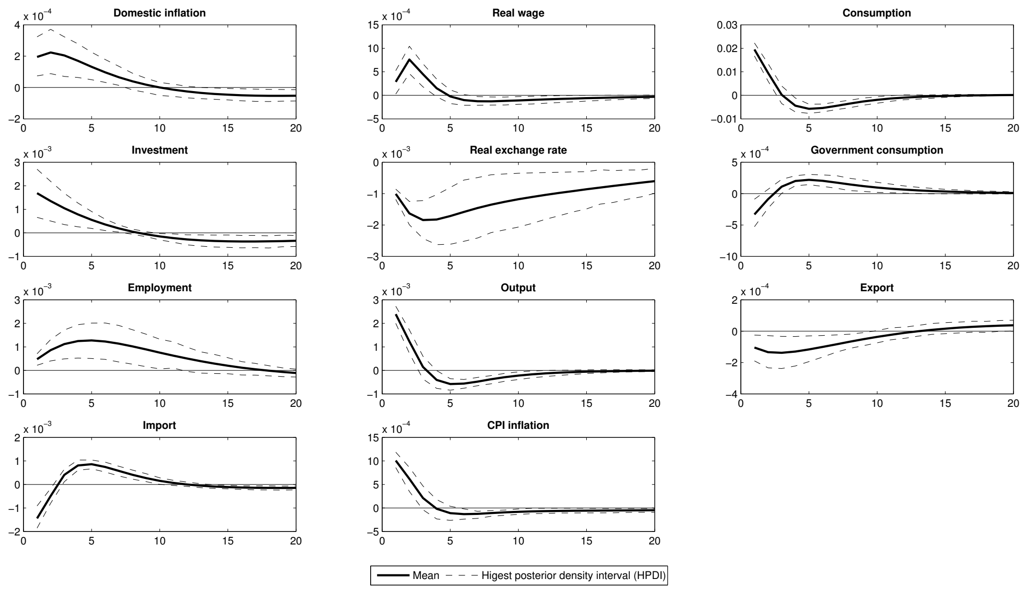
Figure K.6: *Impulse responses to a domestic mark-up shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

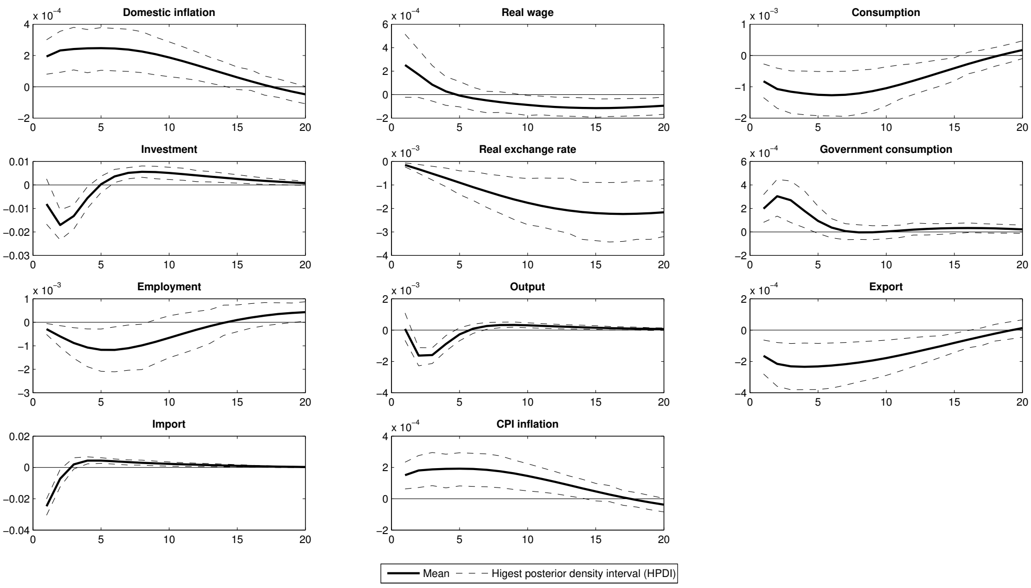
Figure K.7: *Impulse responses to an imported consumption mark-up shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

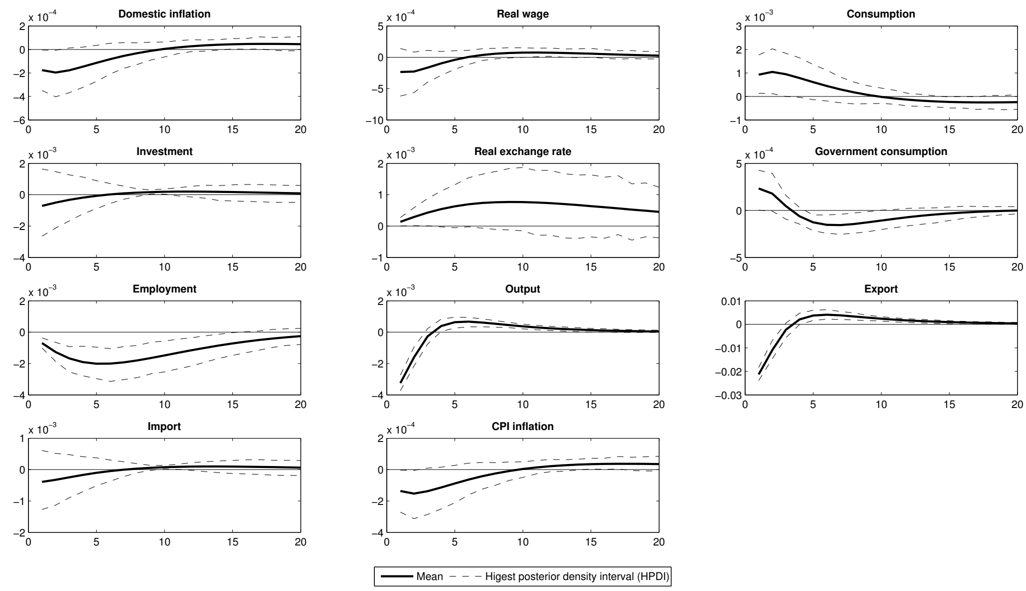
Figure K.8: *Impulse responses to an imported investment mark-up shock*



Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

Figure K.9: *Impulse responses to an export mark-up shock*

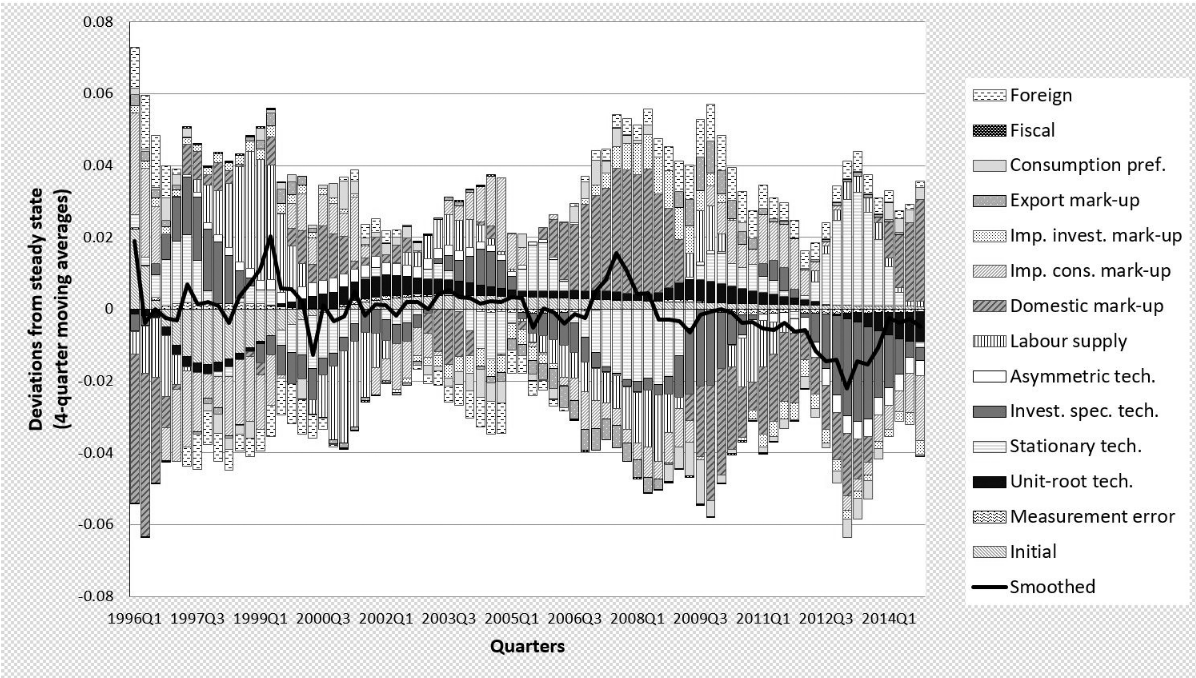


Notes: The solid line shows the average impulse responses results over the MCMC parameter draws; the dashed lines at the 5 % and 95 % posterior intervals. The impulse horizon is measured in quarters.

Source: Own work.

Appendix L. Historical decompositions

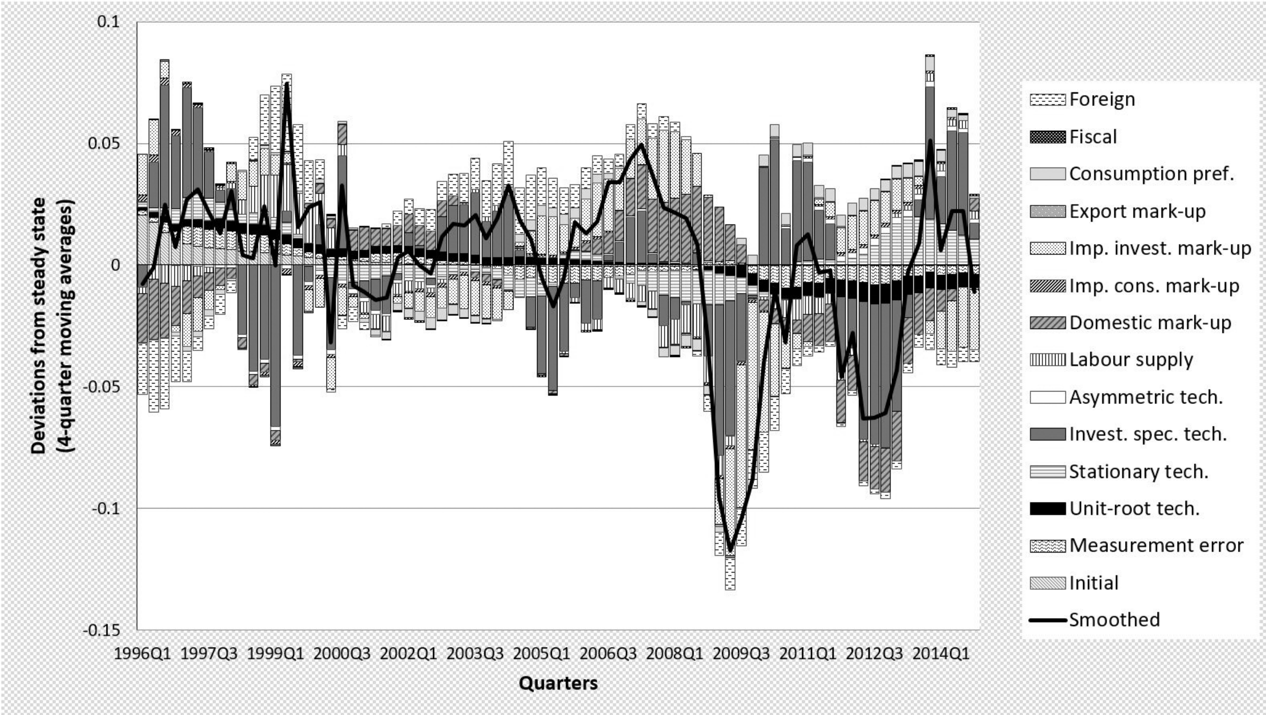
Figure L.1: *Historical decomposition of consumption growth in terms of structural shocks*



Notes: The smoothed observed time series is plotted excluding its mean.

Source: Own work.

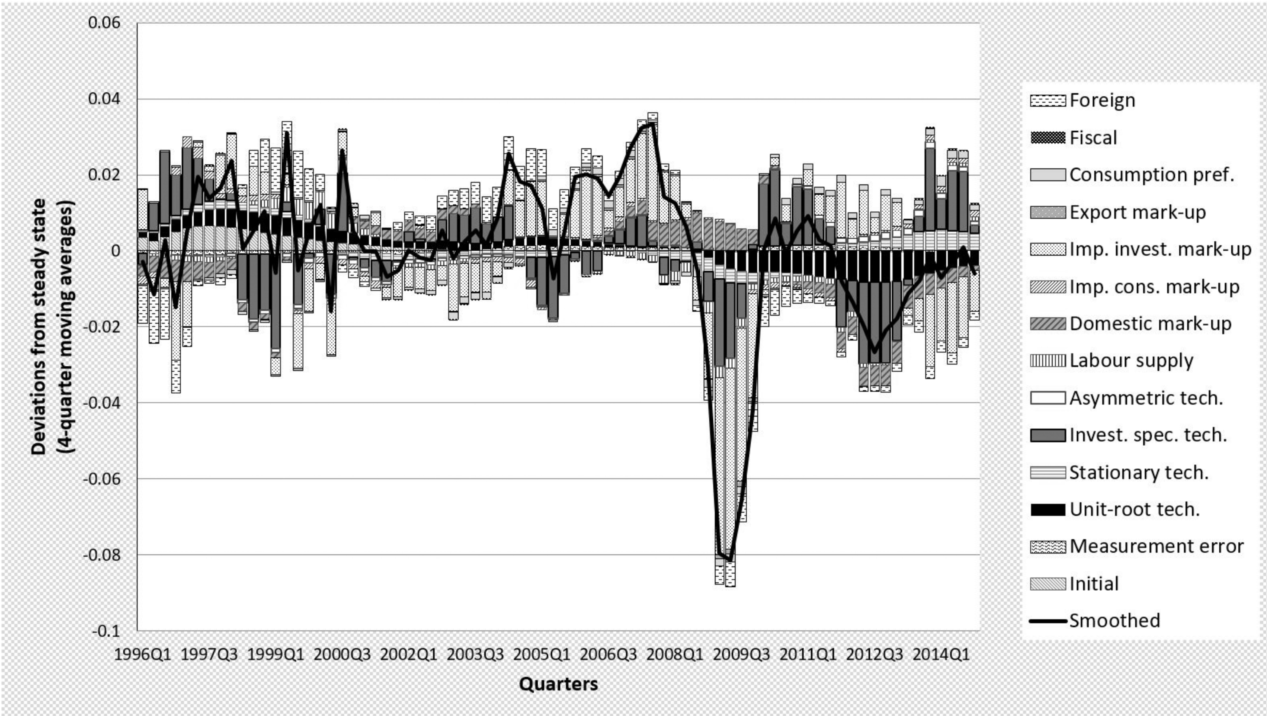
Figure L.2: *Historical decomposition of investment growth in terms of structural shocks*



Notes: The smoothed observed time series is plotted excluding its mean.

Source: Own work.

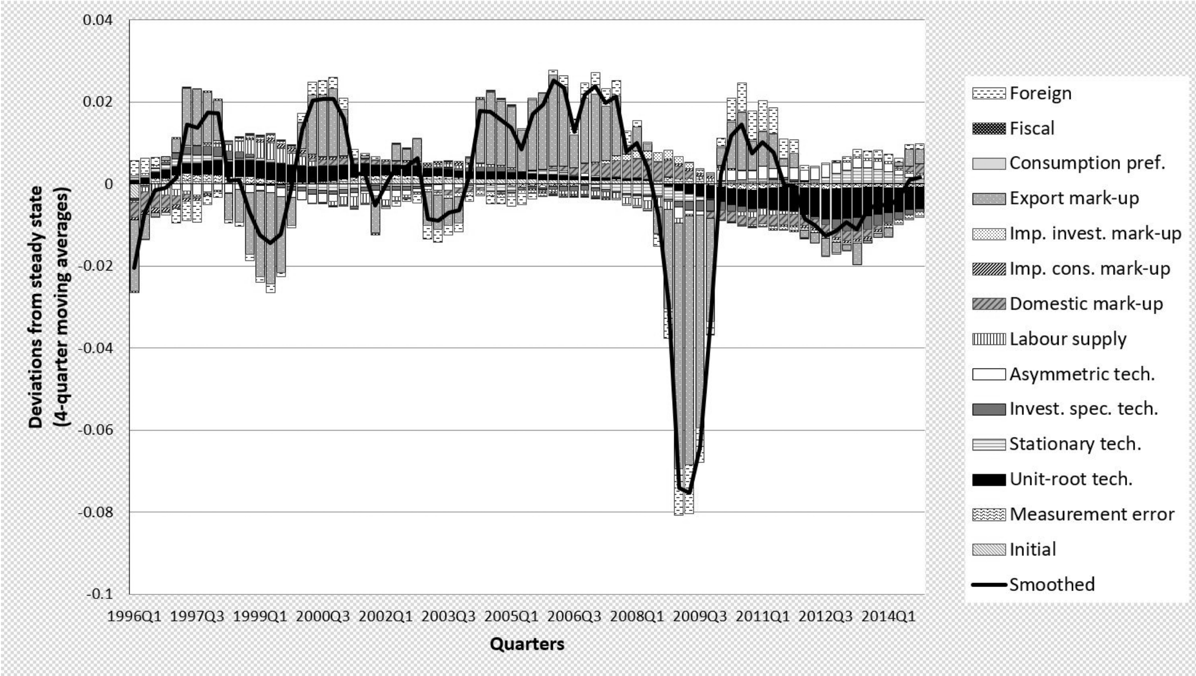
Figure L.3: *Historical decomposition of import growth in terms of structural shocks*



Notes: The smoothed observed time series is plotted excluding its mean.

Source: Own work.

Figure L.4: *Historical decomposition of export growth in terms of structural shocks*



Notes: The smoothed observed time series is plotted excluding its mean.

Source: Own work.

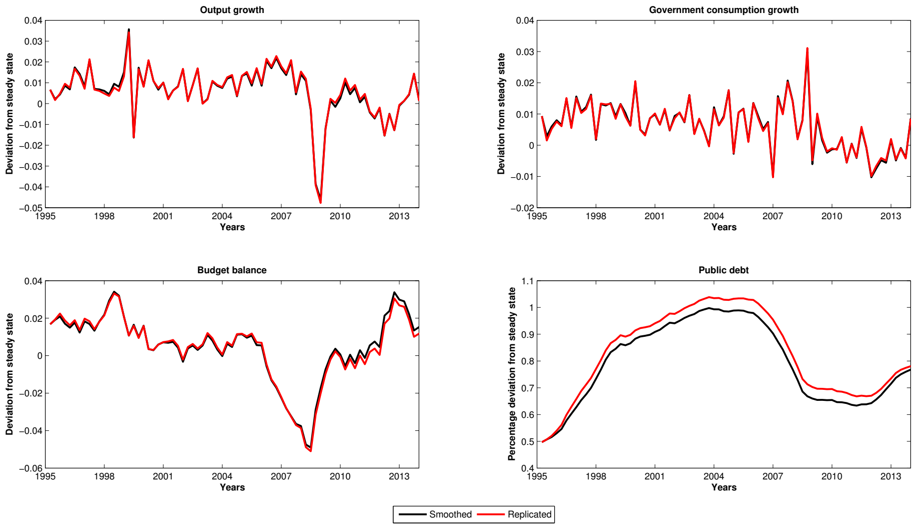
Appendix M. Fiscal rules simulation procedure details

In this appendix, I provide a brief description of the simulation procedure adopted that allows the reader to understand the simulation results provided in the main text of the second chapter. For simulation purposes, I use the function `simult_` supported by Dynare, which is of the following form:

$$\texttt{y\_} = \texttt{simult\_}(\texttt{y0}, \texttt{dr}, \texttt{ex\_}, \texttt{iorder}). \tag{M.1}$$

This function has three main input arguments, the first one (labelled as `y0`) containing the initial values needed to start the simulation, the second one (labelled as `dr`) containing the solution of the model and the third one (labelled as `ex_`) containing the smoothed shock innovations. There is also the forth input argument (labelled as `iorder`) which specifies the order of the Taylor approximation (in my case $\texttt{iroder} = 1$). Before conducting simulation, I show that the simulation with the smoothed shocks replicates the observed (smoothed) variables, which than serves as the basis for simulation of fiscal rules. To this end, the input arguments for the `simult_` function are set as follows: The first thing one need to do is to define the vector of initial values. In order to realize a good replication of smoothed times series, I choose the first smoothed value of the states to construct a vector of initial values. As a second input argument I use the results matrix of the baseline model (i.e. the model which assumes an AR(1) process for the government consumption). Finally, the third argument requires the use of the historical (smoothed) values of shock innovations. For this purpose, I use the mean estimates (i.e. the average smoother results over the MCMC parameter draws) of the smoothed shocks, excluding the first observation due to being initial condition. The function then returns a vector of simulated (replicated) values of each variable included in the model (i.e. `y_`). Figure M.1 plots the smoothed and replicated time series of selected model variables. Ideally, the smoothed and replicated time series should be exactly identical. However, some small differences are observed. This is related to the fact that the steady state values of the model, which are non-linear functions of the model parameters, are calculated at the mean of the parameters, but I would actually need the mean of the steady states.

Figure M.1: *Two-sided (smoothed) Kalman filtered estimates and replicated values of some key variables*



Source: Own work.

Appendix N. Steady state of the model specification with electricity price shocks

The steady state of the model with electricity price shocks is determined by the following set of equations:[67]

The stationary first-order condition for b_{t+1} in steady state reads as:

$$-1+\beta\left[\frac{1}{\mu_z}\frac{1}{\pi}\left(R-\tau^k\left(R-1\right)\right)\right]=0 \tag{N.1}$$

or equivalently:

$$\begin{aligned} R-\tau^k\left(R-1\right)&=\frac{\pi\mu_z}{\beta}\\ &\Leftrightarrow\\ R&=\frac{\pi\mu_z-\tau^k\beta}{\left(1-\tau^k\right)\beta}. \end{aligned} \tag{N.2}$$

The stationarized first-order condition for b^*_{t+1} can be simplified to:

$$-1+\beta\left[\frac{1}{\mu_z\pi}\left(R^*\Phi\left(\frac{A}{z},\tilde{\phi}\right)-\tau^k\left(R^*\Phi\left(\frac{A}{z},\tilde{\phi}\right)-1\right)\right)\right]=0. \tag{N.3}$$

[67]Our presentation closely follows that of Adolfson et al. (2007).

Assuming that:

$$R^* = R, \tag{N.4}$$

it can be seen by comparison of (N.1) and (N.3) that one possible steady state is characterized by:

$$\Phi\left(\frac{A_t}{z_t}, \tilde{\phi}\right) = \Phi\left(\frac{A}{z}, \tilde{\phi}\right) = 1, \tag{N.5}$$

which with the assumption that $\Phi\left(\frac{A}{z}, \tilde{\phi}\right) = \exp\left(-\tilde{\phi}_a A/z + \tilde{\phi}\right)$ implies that $B^* = A = 0$, and $\tilde{\phi} = 0$. Thus, in steady state, the net foreign asset position is zero. Using $F_1 = 1, F_2 = 0, \Upsilon = 1$, the first-order condition for i_t simplifies to:

$$P_{k'} = \frac{P^i}{P^d}. \tag{N.6}$$

To determine the relative prices in steady state, the model assumes that $R = R^*$, $\pi = \pi^*$ and $P_0 = P_0^*$. The latter assumption means that the steady state price levels in the beginning of time were the same. The steady state relative prices are defined as:

$$\gamma_t^{c,d} \equiv \frac{P_t^c}{P_t^d} = \left(\frac{P_t^z}{P_t^d}\right)^{1-\omega_e} \left(\frac{P_t^{e,c}}{P_t^d}\right)^{\omega_e} \tag{N.7}$$

$$\gamma^{c,d} \equiv \frac{P^c}{P^d} = \left(\gamma^{z,d}\right)^{1-\omega_e} \left(\gamma^{ec,d}\right)^{\omega_e} \tag{N.8}$$

$$\gamma_t^{z,d} \equiv \frac{P_t^z}{P_t^d} = \left[(1-\omega_c) + \omega_c \left(\frac{P_t^{m,c}}{P_t^d}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)} \tag{N.9}$$

$$\gamma_t^{z,mc} \equiv \frac{P_t^z}{P_t^{m,c}} = \left[(1-\omega_c) \left(\frac{P_t^d}{P_t^{m,c}}\right)^{1-\eta_c} + \omega_c\right]^{1/(1-\eta_c)} \tag{N.10}$$

$$\gamma^{z,d} = \left[(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\frac{P^*}{P^d}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)} \tag{N.11}$$

$$\gamma^{z,mc} = \left[(1-\omega_c) \left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\frac{P^d}{P^*}\right)^{1-\eta_c} + \omega_c\right]^{1/(1-\eta_c)} \tag{N.12}$$

$$\gamma^{z,d} = \left[(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1}\right)^{1-\eta_c}\right]^{1/(1-\eta_c)} \tag{N.13}$$

$$\gamma^{z,mc} = \left[(1-\omega_c) \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right)^{1-\eta_c} + \omega_c \right]^{1/(1-\eta_c)} \tag{N.14}$$

$$\gamma^{i,d} \equiv \frac{P^i}{P^d} = \left[(1-\omega_i) + \omega_i \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i} \right]^{1/(1-\eta_i)} \tag{N.15}$$

$$\gamma^{i,mi} \equiv \frac{P^i}{P^{m,i}} = \left[(1-\omega_i) \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i} + \omega_i \right]^{1/(1-\eta_i)}. \tag{N.16}$$

Combining equations (N.9) and (N.10), it follows that:

$$\frac{P^{m,c}}{P^d} = \left[\frac{(1-\omega_c) + \omega_c \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right)^{1-\eta_c}}{(1-\omega_c) \left(\frac{\eta^{m,c}}{\eta^{m,c}-1} \right)^{1-\eta_c} + \omega_c} \right]^{1/(1-\eta_c)} = \frac{\eta^{m,c}}{\eta^{m,c}-1} \tag{N.17}$$

while equations (N.15) and (N.16) give:

$$\frac{P^{m,i}}{P^d} = \left[\frac{(1-\omega_i) + \omega_i \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i}}{(1-\omega_i) \left(\frac{\eta^{m,i}}{\eta^{m,i}-1} \right)^{1-\eta_i} + \omega_i} \right]^{1/(1-\eta_i)} = \frac{\eta^{m,i}}{\eta^{m,i}-1}. \tag{N.18}$$

Furthermore, the model assumes that the export price equals the foreign price level in steady state $P^x = P^*$, which implies that the steady state mark-up in the export market must be one:

$$P^x = P^d. \tag{N.19}$$

Using $P_{k'} = \frac{P^i}{P^d}$ and $u_t = \frac{k_t}{\bar{k}_t} = u = 1 \Rightarrow a(u) = a(1) = 0$ in the first-order condition for $\bar{k}_{t+1}$, it is possible to obtain:

$$\begin{aligned} \beta \left[\frac{1}{\mu_z} (1-\delta) P_{k'} + \left(1-\tau^k\right) r^k \right] &= P_{k'} \\ &\Leftrightarrow \\ r^k &= \frac{\mu_z P_{k'} - \beta (1-\delta) P_{k'}}{(1-\tau^k)\beta}. \end{aligned} \tag{N.20}$$

Using the scaled equilibrium rental rate of capital, it follows that:

$$r^k = \frac{\alpha (1-\delta_e)}{1-\alpha} \mu_z \bar{w} R^f \frac{H}{k}. \tag{N.21}$$

Next, the steady state relative price between the electricity for firms and the domestically produced goods (domestic consumption) is determined by:

$$\gamma^{ed,d} = \frac{\delta_e}{1-\delta_e} r^k \frac{k}{e^d} \mu_z^{-1}. \tag{N.22}$$

Using that:

$$P^d = \lambda^d MC \tag{N.23}$$

in steady state, or equivalently:

$$\frac{MC}{P} = \frac{1}{\lambda^d}, \tag{N.24}$$

it follows from the equilibrium real marginal cost:

$$\frac{1}{\lambda^d} = \left(\frac{1}{1-\alpha}\right)^{(1-\alpha)} \left(\frac{1}{\alpha\left(1-\delta_e\right)}\right)^{\alpha(1-\delta_e)} \left(\frac{1}{\alpha\delta_e}\right)^{\alpha\delta_e} \left(r^k\right)^{\alpha(1-\delta_e)} \left(\gamma^{ed,d}\right)^{\alpha\delta_e} \left(\bar{w}R^f\right)^{(1-\alpha)}. \tag{N.25}$$

Real profit for domestic firm is given by:

$$\Pi^d \equiv \left(\frac{P^d}{MC}\right) y - r^k \frac{k}{\mu_z} - \bar{w}R^f H - \gamma^{ed,d} e^d - \phi. \tag{N.26}$$

Under perfect competition there is no markup (profits are zero), and y must equal $y = r^k \frac{k}{\mu_z} - \bar{w}R^f H - \gamma^{ed,d} e^d$. To impose $\Pi^d = 0$ in steady state also in monopolistic case, the size of the fixed cost, ϕ, needs to be determined such that this zero profit condition is fulfilled. The zero profit condition reduces to:

$$\Pi^d \equiv \lambda^d y - y - \phi = 0 \tag{N.27}$$

or equivalently:

$$\phi = \left(\lambda^d - 1\right) y. \tag{N.28}$$

Another way to write above condition is to use the steady-state version of production function:

$$\phi = \left(\lambda^d - 1\right) \left[\left(\frac{1}{\mu_z}\right)^{\alpha(1-\delta_e)} k^{\alpha(1-\delta_e)} \left(e^d\right)^{\alpha\delta_e} H^{(1-\alpha)} - \phi\right] \tag{N.29}$$

or equivalently:

$$\phi = \frac{\lambda^d - 1}{\lambda^d} \left(\frac{1}{\mu_z}\right)^{\alpha(1-\delta_e)} \left(\frac{e^d}{k}\right)^{\alpha\delta_e} \left(\frac{k}{H}\right)^{\alpha} H. \tag{N.30}$$

From the law of motion for capital, it follows in steady state:

$$k = \frac{1-\delta}{\mu_z} k + i \tag{N.31}$$

or equivalently:

$$i = \left(1 - \frac{1-\delta}{\mu_z}\right) k. \tag{N.32}$$

The consumption Euler equation in steady state is given by:

$$\frac{1}{c - bc\frac{1}{\mu_z}} - \beta b \frac{1}{c\mu_z - bc} - \psi_z \frac{P^c}{P^d}\left(1+\tau^c\right) = 0 \tag{N.33}$$

or equivalently:

$$\psi_z = \frac{1}{c}\frac{\mu_z - \beta b}{\left(1+\tau^c\right)\left(\mu_z - b\right)}\left(\frac{P^c}{P^d}\right)^{-1}. \tag{N.34}$$

The first order condition for the households labour decision in steady state reads as:

$$-A_L H^{\sigma_L} + \left(1-\tau^y\right)\frac{\psi_z}{\lambda^w}\bar{w} = 0 \tag{N.35}$$

or equivalently:

$$H = \left[\frac{\left(1-\tau^y\right)\frac{\psi_z}{\lambda^w}\bar{w}}{A_L}\right]^{1/\sigma_L}. \tag{N.36}$$

The resource constraint in steady-state is given by:

$$c^d + i^d + c^x + i^x = \left(1-g_r\right)\left[\left(\frac{1}{\mu_z}\right)^{\alpha(1-\delta_e)}\left(\frac{e^d}{k}\right)^{\alpha\delta_e}\left(\frac{k}{H}\right)^{\alpha} H - \phi\right]. \tag{N.37}$$

Using demand functions for domestic consumption goods and domestic investment goods, yields:

$$\begin{aligned}
&\left(1-\omega_c\right)\left(\frac{P^z}{P^d}\right)^{\eta_c} c^z + \left(1-\omega_i\right)\left(\frac{P^i}{P^d}\right)^{\eta_i} i + c^x + i^x \\
&= \frac{\left(1-g_r\right)}{\lambda^d}\left(\frac{1}{\mu_z}\right)^{\alpha(1-\delta_e)}\left(\frac{e^d}{k}\right)^{\alpha\delta_e}\left(\frac{k}{H}\right)^{\alpha} H.
\end{aligned} \tag{N.38}$$

Furthermore, the model assumes that export equals import in steady-state which is consistent with a zero foreign debt in steady-state. From the equation that describes the evolution of net foreign assets at the aggregate level, it follows that:

$$c^m + i^m = c^x + i^x. \tag{N.39}$$

Using the demand functions for imported consumption goods and imported investment goods evaluated in steady state:

$$c^m = \omega_c\left(\frac{P^{m,c}}{P^z}\right)^{-\eta_c} c^z = \omega_c\left(\frac{P^z}{P^{m,c}}\right)^{\eta_c} c^z \tag{N.40}$$

$$i^m = \omega_i\left(\frac{P^{m,i}}{P^i}\right)^{-\eta_i} i = \omega_i\left(\frac{P^i}{P^{m,i}}\right)^{\eta_i} i, \tag{N.41}$$

the above condition can be rewritten as:

$$\omega_c\left(\frac{P^z}{P^{m,c}}\right)^{\eta_c} c^z + \omega_i\left(\frac{P^i}{P^{m,i}}\right)^{\eta_i} i = c^x + i^x \tag{N.42}$$

$$\omega_c \left(\frac{P^z}{P^{m,c}}\right)^{\eta_c} c^z + \omega_i \left(\frac{P^i}{P^{m,i}}\right)^{\eta_i} i = \tilde{x}. \tag{N.43}$$

Inserting the steady state law of motion for capital into resource constraint, yields:

$$\begin{aligned}
&\left[(1-\omega_c)\left(\frac{P^z}{P^d}\right)^{\eta_c} + \omega_c \left(\frac{P^z}{P^{m,c}}\right)^{\eta_c}\right] c^z \\
&+ \left[(1-\omega_i)\left(\frac{P^i}{P^d}\right)^{\eta_i} + \omega_i \left(\frac{P^i}{P^{m,i}}\right)^{\eta_i}\right] \left(1 - \frac{1-\delta}{\mu_z}\right)\left(\frac{k}{H}\right) H \\
&= \frac{(1-g_r)}{\lambda^d}\left(\frac{1}{\mu_z}\right)^{\alpha(1-\delta_e)}\left(\frac{e^d}{k}\right)^{\alpha\delta_e}\left(\frac{k}{H}\right)^{\alpha} H.
\end{aligned} \tag{N.44}$$

In order to calculate the steady-state values of H, c and ψ_z, the following definitions have to be introduced:

$$D_1 \equiv (1-\omega_c)\left[\frac{P^z}{P^d}\right]^{\eta_c} + \omega_c \left[\frac{P^z}{P^{m,c}}\right]^{\eta_c} \tag{N.45}$$

$$\begin{aligned}
D_2 \equiv \Bigg[&\frac{(1-g_r)}{\lambda^d}\left(\frac{1}{\mu_z}\right)^{\alpha(1-\delta_e)}\left(\frac{e^d}{k}\right)^{\alpha\delta_e}\left(\frac{k}{H}\right)^{\alpha} \\
&- \left((1-\omega_i)\left[\frac{P^i}{P^d}\right]^{\eta_i} + \omega_i \left[\frac{P^i}{P^{m,i}}\right]^{\eta_i}\right)\left(1 - \frac{1-\delta}{\mu_z}\right)\left(\frac{k}{H}\right)\Bigg]
\end{aligned} \tag{N.46}$$

$$D_3 \equiv \left[\frac{(1-\tau^y)\frac{1}{\lambda^w}\bar{w}}{A_L}\right]^{1/\sigma_L} \tag{N.47}$$

$$D_4 \equiv \frac{\mu_z - \beta b}{(1+\tau^c)(\mu_z - b)}\left(\frac{P^c}{P^d}\right)^{-1}. \tag{N.48}$$

Then, the following system can be derived:

$$D_1 c^z = D_2 H \tag{N.49}$$

$$H = D_3 (\psi_z)^{1/\sigma_L} \tag{N.50}$$

$$\psi_z = \frac{1}{c} D_4 \tag{N.51}$$

and the solutions for H, c and ψ_z are given by:

$$H = \left[D_3 D_4^{1/\sigma_L}\left(\frac{D_2}{D_1}\right)^{-1/\sigma_L}(1-\omega_e)^{1/\sigma_L}\left(\frac{\gamma^{c,d}}{\gamma^{z,d}}\right)^{1/\sigma_L}\right]^{\frac{\sigma_L}{1+\sigma_L}} \tag{N.52}$$

$$c = \frac{D_2 \gamma^{z,d}}{D_1 (1-\omega_e)\gamma^{c,d}} H \tag{N.53}$$

$$\psi_z = \frac{1}{c} D_4. \tag{N.54}$$

Once obtained the solution for H, y can be computed as:

$$y = \frac{1}{\lambda^d}\left(\frac{1}{\mu_z}\right)^{\alpha(1-\delta_e)}\left(\frac{e^d}{k}\right)^{\alpha\delta_e}\left(\frac{k}{H}\right)^{\alpha} H \tag{N.55}$$

using the solution for $\frac{k}{H}$ and $\frac{e^d}{k}$. ϕ is computed using (N.30) and steady state government consumption as:

$$g = g_r y. \tag{N.56}$$

The first-order condition for the capital utilization rate evaluated in steady state equals:

$$a'(1) = \left(1-\tau^k\right) r^k. \tag{N.57}$$

Appendix O. Complete model in log-linearized form (the model specification with electricity price shocks)

In this appendix, I present the log-linearized version of the model specification with electricity price shocks. In order to save space, I only present the equations that are new compared to the baseline model specification presented in Appendix D.

Real marginal costs for domestic firms:

$$\widehat{mc}_t = (1-\delta_e)\,\alpha\hat{r}_t^k + \alpha\delta_e\hat{\gamma}_t^{ed,d} + (1-\alpha)\,\hat{\bar{w}}_t - \hat{\epsilon}_t. \tag{O.1}$$

Aggregate resource constraint:

$$\begin{aligned}(1-\omega_c)\left(\gamma^{z,d}\right)^{\eta_c}\frac{c^z}{y}\left(\hat{c}_t^z+\eta_c\hat{\gamma}_t^{z,d}\right)+(1-\omega_i)\left(\gamma^{i,d}\right)^{\eta_i}\frac{i}{y}\left(\hat{i}_t+\eta_i\hat{\gamma}_t^{i,d}\right)+\frac{g}{y}\hat{g}_t \\ +\frac{y^*}{y}\left(\hat{y}_t^*-\eta_f\hat{\gamma}_t^{x,*}+\hat{\tilde{z}}_t^*\right) \\ =\lambda^d\left[\hat{\varepsilon}_t+\alpha(1-\delta_e)\left(\hat{k}_t-\hat{\mu}_{z,t}\right)+\alpha\delta_e\hat{e}_t+(1-\alpha)\hat{H}_t\right] \\ -\left(1-\tau^k\right)r^k\frac{\bar{k}}{y}\frac{1}{\mu_z}\left(\hat{k}_t-\hat{\bar{k}}_t\right).\end{aligned} \tag{O.2}$$

Equilibrium law of motion for net foreign assets:

$$\begin{aligned}\hat{a}_t = &-y^*\widehat{mc}_t^x-\eta_f y^*\hat{\gamma}_t^{x,*}+y^*\hat{y}_t^*+y^*\hat{\tilde{z}}_t^*+\left(c^m+i^m\right)\hat{\gamma}_t^f \\ &-c^m\left[-\eta_c(1-\omega_c)\left(\gamma^{z,d}\right)^{-(1-\eta_c)}\hat{\gamma}_t^{mc,d}+\hat{c}_t^z\right] \\ &+i^m\left[-\eta_i(1-\omega_i)\left(\gamma^{i,d}\right)^{-(1-\eta_i)}\hat{\gamma}_t^{mi,d}+\hat{i}_t\right]+\frac{R}{\pi\mu_z}\hat{a}_{t-1}.\end{aligned} \tag{O.3}$$

Gross domestic product:

$$\hat{y}_t = \lambda^d\left[\hat{\varepsilon}_t+\alpha(1-\delta_e)\left(\hat{k}_t-\hat{\mu}_{z,t}\right)+\alpha\delta_e\hat{e}_t+(1-\alpha)\hat{H}_t\right]. \tag{O.4}$$

CPI inflation:

$$\hat{\pi}_t^c = (1-\omega_e)\,\hat{\pi}_t^c + \omega_e\hat{\pi}_t^{e,c}. \tag{O.5}$$

Core CPI inflation:

$$\hat{\pi}_t^z = \left[(1-\omega_c)\left(\gamma^{d,z}\right)^{1-\eta_c}\right]\hat{\pi}_t + \left[(\omega_c)\left(\gamma^{mc,c}\right)^{1-\eta_c}\right]\hat{\pi}_t^{m,c}. \tag{O.6}$$

Demand for core consumption:

$$\hat{c}_t^z = -\hat{\gamma}_t^{z,c} + \hat{c}_t. \tag{O.7}$$

Households' demand for electricity:

$$\hat{c}_t^e = -0.05\hat{\gamma}_t^{e,c} + \hat{c}_t. \tag{O.8}$$

Demand for domestic consumption goods:

$$\hat{c}_t^d = -\eta_c\hat{\gamma}_t^{d,z} + \hat{c}_t^z. \tag{O.9}$$

Firms' demand for electricity:

$$\hat{e}_t^d = \hat{\bar{w}}_t + \hat{R}_t^f + \hat{H}_t - \hat{\gamma}_t^{ed,d}. \tag{O.10}$$

Total demand for electricity:

$$\begin{aligned}\hat{y}_t^{d,e} &= s_d\hat{e}_t^d + (1-s_d)\,\hat{c}_t^e \\ &= \omega_{em}\hat{m}_t^e + (1-\omega_{em})\,\hat{y}_t^{s,e}.\end{aligned} \tag{O.11}$$

Relative price between the electricity for firms and the domestically produced goods (domestic consumption):

$$\hat{\gamma}_t^{ed,d} = \hat{\gamma}_{t-1}^{ed,d} + \hat{\pi}_t^{e,d} - \hat{\pi}^d. \tag{O.12}$$

Electricity price inflation for industrial consumers:

$$\hat{\pi}_t^{e,d} = \alpha_e\hat{\pi}_{t-1}^{e,d} - \alpha_\gamma\hat{\gamma}_{t-1}^{ed,d} + \varepsilon_t^{ed,d}.$$

Structure of electricity price for industrial consumers:

$$\varepsilon_t^{ed,d} = \omega_{ed1}\varepsilon_{\text{price},t}^{e,d} + \omega_{ed2}\varepsilon_{\text{use-of-network},t}^{e,d} + \omega_{ed3}\varepsilon_{\text{contributions},t}^{e,d} + \omega_{ed4}\varepsilon_{\text{excise},t}. \tag{O.13}$$

Price inflation for electricity produced from domestic resources:

$$\hat{\pi}_t^{e,h} = \hat{\pi}_t^{e,d}. \tag{O.14}$$

Relative price between the electricity for households and the domestically produced goods (domestic consumption):

$$\hat{\gamma}_t^{ec,d} = \hat{\gamma}_{t-1}^{ec,d} + \hat{\pi}_t^{e,c} - \hat{\pi}^d. \tag{O.15}$$

Electricity price inflation for household consumers:

$$\hat{\pi}_t^{e,c} = \alpha_e \hat{\pi}_{t-1}^{e,c} - \alpha_\gamma \hat{\gamma}_{t-1}^{ec,d} + \varepsilon_t^{ec,d}.$$

Structure of electricity price for household consumers:

$$\varepsilon_t^{ec,d} = \omega_{ec1} \varepsilon_{\text{price},t}^{e,c} + \omega_{ec2} \varepsilon_{\text{use-of-network},t}^{e,c} + \omega_{ec3} \varepsilon_{\text{contributions},t}^{e,c} + \omega_{ec4} \varepsilon_{\text{excise},t}. \tag{O.16}$$

Relative price between the electricity households and the CPI index:

$$\hat{\gamma}_t^{ec,c} = -\left(1-\omega_e\right)\left[\left(1-\omega_c\right)\left(\hat{\gamma}^{d,z}\right)^{1-\eta_c}\left(-\hat{\gamma}_t^{ec,d}\right) + \omega_c \left(\hat{\gamma}^{mc,c}\right)^{1-\eta_c}\left(\hat{\gamma}_t^{mc,d} - \hat{\gamma}_t^{ec,d}\right)\right]. \tag{O.17}$$

Relative price between the core CPI index and CPI index:

$$\hat{\gamma}_t^{z,c} = \omega_e\left[\left(1-\omega_e\right)\left(\hat{\gamma}^{d,z}\right)^{1-\eta_c}\left(-\hat{\gamma}_t^{ec,d}\right) + \omega_e \left(\hat{\gamma}^{mc,c}\right)^{1-\eta_c}\left(\hat{\gamma}_t^{mc,d} - \hat{\gamma}_t^{ec,d}\right)\right]. \tag{O.18}$$

Total tax revenue:

$$\hat{t}_t = \frac{\tau^c t^a}{t}\hat{t}_t^a + \frac{\tau^y t^b}{t}\hat{t}_t^b + \frac{\tau^k}{t}\left(\tilde{t}_t^c + \tilde{t}_t^d + \tilde{t}_t^e + \tilde{t}_t^f\right) + \frac{\tau^{excise} y^{d,e}}{t}\hat{t}_t^{excise}. \tag{O.19}$$

Excise duty on electricity:

$$\hat{t}_t^{excise} = \hat{\tau}_t^{excise} + \hat{y}_t^{d,e}. \tag{O.20}$$

Relative prices:

$$\hat{\gamma}_t^{mz,d} = \hat{\gamma}_{t-1}^{mz,d} + \hat{\pi}_t^{m,z} - \hat{\pi}_t^d \tag{O.21}$$

$$\hat{\gamma}_t^{c,d} = \left(1-\omega_e\right)\hat{\gamma}_t^{z,d} + \omega_e \hat{\gamma}_t^{ec,d} \tag{O.22}$$

$$\hat{\gamma}_t^{z,d} = \omega_c \left(\gamma^{mc,c}\right)^{(1-\eta_c)} \hat{\gamma}_t^{mc,d}. \tag{O.23}$$

Appendix P. Graphical user interface for the model with electricity

Figure P.1: *Graphical user interface - basic*

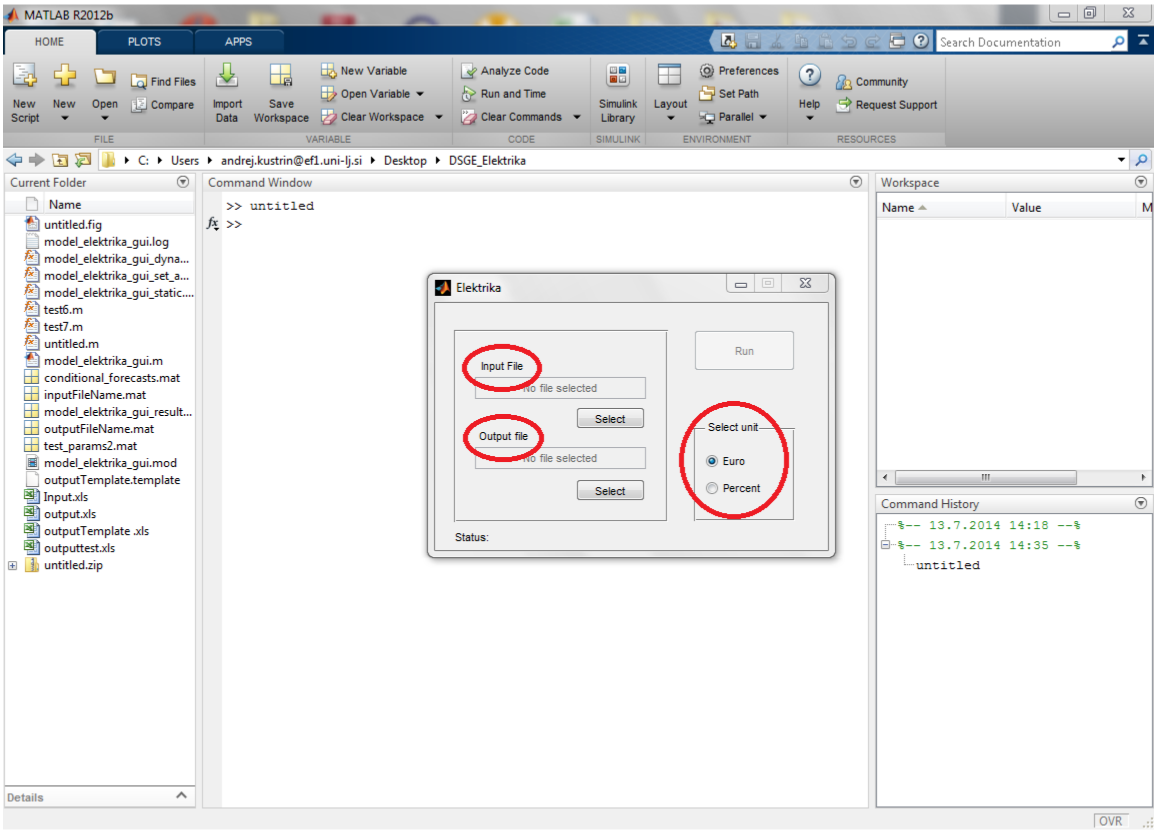
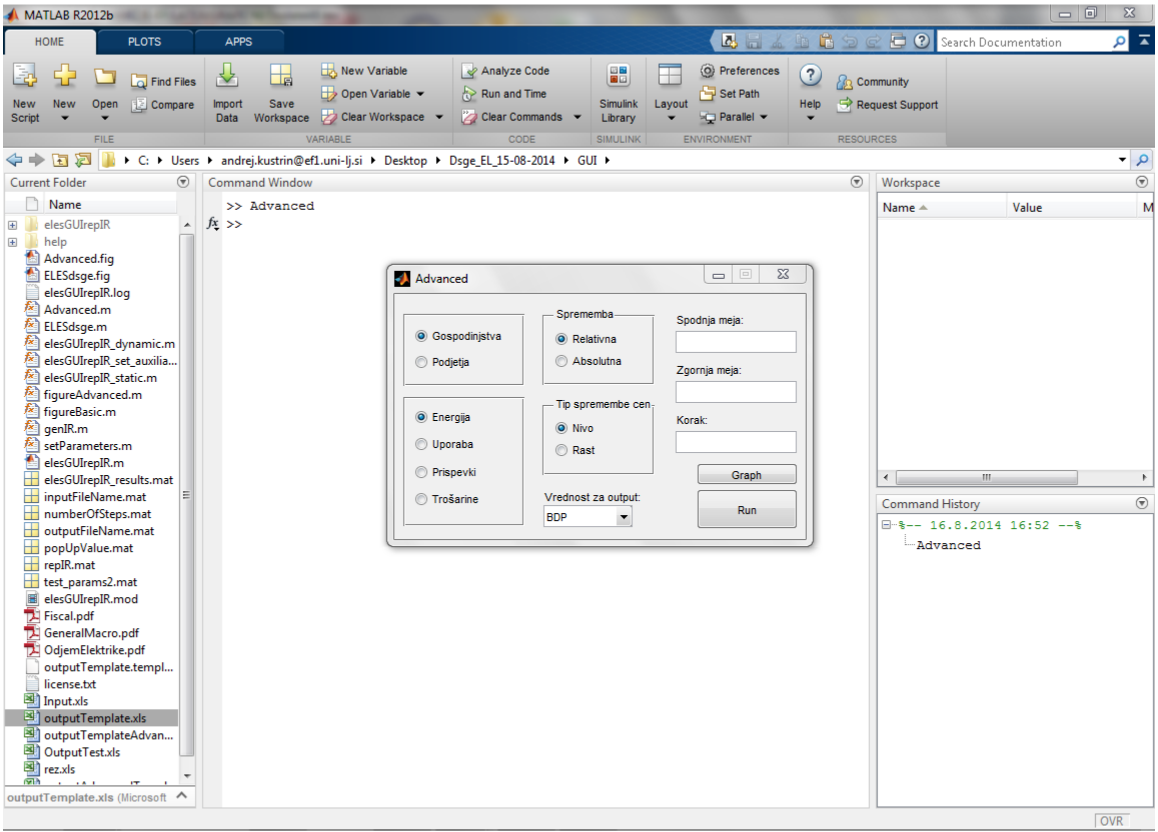


Figure P.2: *Graphical user interface - advanced*



Appendix Q. Description of variables used in the model (the baseline model specification & the model specification with electricity price shocks)

Table Q.1: *Description of variables used in the model*

Variable	Description
$\hat{\pi}_t$	Inflation domestic good prices
$\hat{\pi}_t^{m,c}$	Inflation import consumption good prices
$\hat{\pi}_t^{m,i}$	Inflation import investment good prices
$\hat{\pi}_t^{x}$	Inflation export good prices
$\hat{\pi}_t^{c}$	CPI inflation
$\widehat{mc}_t$	Real marginal cost for domestic firms
$\widehat{mc}_t^{m,c}$	Real marginal cost for imported consumption goods
$\widehat{mc}_t^{m,i}$	Real marginal cost for imported investment goods
$\widehat{mc}_t^{x}$	Real marginal cost for exporting firms
$\hat{r}_t^k$	Rental rate of capital
$\hat{\lambda}_t^d$	Markup domestic prices
$\hat{\lambda}_t^{m,c}$	Markup import consumption prices
$\hat{\lambda}_t^{m,i}$	Markup import investment prices
$\hat{\lambda}_t^{x}$	Markup export prices
$\hat{\mu}_{z,t}$	Growth of unit-root technology
$\hat{\bar{w}}_t$	Stationary real wage
$\hat{\epsilon}_t$	Stationary technology
$\hat{H}_t$	Hours worked
$\hat{k}_t$	Capital services
$\hat{\gamma}_t^{x,*}$	Relative price between the domestically produced goods (home exports) and the foreign goods
$\hat{\gamma}_t^{mc,d}$	Relative price between the imported consumption goods and the domestically produced goods
$\hat{\gamma}_t^{mi,d}$	Relative price between the imported investment goods and the domestically produced goods

Table continued on next page

Variable	Description
$\hat{\psi}_{z,t}$	Real Lagrangian multiplier
$\hat{\zeta}^h_t$	Labour supply shock
$\hat{c}_t$	Consumption
$\hat{\gamma}^{c,d}_t$	Relative price between the CPI and the domestically produced goods
$\hat{\zeta}^c_t$	Consumption preference shock
$\hat{P}_{k',t}$	Price of capital
$\hat{\Upsilon}_t$	Investment-specific technology shock
$\hat{\gamma}^{i,d}_t$	Relative price between the investment goods and the domestically produced goods
$\hat{i}_t$	Investment
$\hat{R}_t$	Domestic interest rate
$\hat{R}^*_t$	Foreign interest rate
$\hat{\tilde{\phi}}_t$	Risk premium
$\hat{a}_t$	Net foreign assets
$\hat{\bar{k}}_t$	Physical capital
$\hat{u}_t$	Capital utilization rate
$\hat{g}_t$	Government consumption
$\hat{y}^*_t$	Foreign output
$\hat{\tilde{z}}^*_t$	Asymmetric technology shock
$\hat{\gamma}^f_t$	Relative price between the domestically produced goods and the foreign goods
$\hat{y}_t$	Gross domestic product
$\hat{x}_t$	Real exchange rate
$\hat{E}_t$	Employment
$\hat{\pi}^*_t$	Foreign inflation
$\hat{b}_t$	Public debt
$\widehat{ben}_t$	Transfers
$\widehat{rr}_t$	Replacement rate
$\widehat{gex}_t$	Government expenditures

Table continued on next page

Variable	Description
$\widetilde{def}_t$	Deficit
$\hat{t}_t$	Total tax revenues
$\hat{t}_t^a$	Tax on consumption
$\hat{t}_t^b$	Taxes and contributions on wages
$\tilde{t}_t^c$	Public debt interest payments
$\tilde{t}_t^d$	Interest on the amount of the capital services
$\tilde{t}_t^e$	Interest on the amount of foreign bond holdings
$\tilde{t}_t^f$	Firms' profit
$\hat{\pi}_t^z$	Inflation domestically produced and imported consumption goods
$\hat{\pi}_t^{e,c}$	Inflation electricity for household consumers
$\hat{\pi}_t^{e,h}$	Inflation domestically produced electricity
$\hat{\pi}_t^{e,f}$	Inflation imported electricity
$\hat{\gamma}_t^{ed,d}$	Relative price between the electricity for industrial consumers and domestically produced goods
$\hat{\gamma}_t^{ec,d}$	Relative price between the electricity for household consumers and domestically produced goods
$\hat{\pi}_t^{e,d}$	Inflation electricity for business consumers
$\hat{\gamma}_t^{z,d}$	Relative price between the consumption goods and domestically produced goods
$\hat{\gamma}_t^{d,z}$	Relative price between the domestically produced goods and consumption goods
$\hat{\gamma}_t^{z,c}$	Ratio between the CPI, excluding electricity, and CPI, including electricity
$\hat{c}_t^z$	Household demand for domestically produced and imported consumption goods
$\hat{c}_t^d$	Household demand for domestically produced goods
$\hat{\gamma}_t^{ec,c}$	Relative price between the electricity price for household consumers and the overall CPI
$\hat{c}_t^e$	Demand for electricity by household consumers
$\hat{e}_t^d$	Demand for electricity by industrial consumers
$\hat{m}_t^e$	Import of electricity
$\hat{y}_t^{d,e}$	Total domestic demand for electricity
$\hat{y}_t^{s,e}$	Supply of domestically produced electricity
$\varepsilon_{ec,d,t}$	Electricity price structure for household consumers
$\varepsilon_{ed,d,t}$	Electricity price structure for industrial consumers

Table continued on next page

Variable	Description

Appendix R. Summary in Slovenian language/Daljši povzetek v slovenskem jeziku

Naslov doktorske disertacije: Dinamični stohastični modeli splošnega ravnotežja in njihova uporaba

Opis raziskovalnega področja doktorske disertacije

Dinamični stohastični modeli splošnega ravnotežja (DSGE) so postali eno izmed pogosto uporabljenih metodoloških orodij za analizo različnih ekonomskih vprašanj v številnih institucijah. Njihova glavna značilnost je, da izhajajo iz mikroekonomskih temeljev - optimizacijskih odločitev ekonomskih subjektov ob upoštevanju omejitev, in ob prisotnosti nepopolne konkurence in različnih rigidnosti.[68] Začetki teorije splošnega ravnotežja segajo v zgodnja 70. leta, ko so ekonomisti pričeli z izgradnjo prvih vzorčnih modelov racionalnih pričakovanj, ki jih lahko razumemo kot predhodnike današnjih DSGE modelov. Ekonomisti so z njimi želeli odgovoriti na Lucasovo kritiko, ki pravi, da je o učinkih sprememb v ekonomski politiki naivno sklepati na podlagi povezav, ki izhajajo iz historičnih podatkov (Lucas, 1976). Prvi celovit makroekonomski model, znan tudi pod imenom model realnih poslovnih ciklov (angl. *Real Business Cycle models - RBC*), sta predstavila Kydland in Prescott (1982). Kljub temu, da so bili tovrstni modeli uspešni pri repliciranju določenih empiričnih zakonitosti gospodarstev, so bili deležni številnih kritik, pri čemer se najpogosteje omenjajo (Mankiw, 1989): (i) poudarjena vloga tehnoloških čokov kot glavnih virov makroekonomskih nihanj; (ii) modeliranje gospodarstva v okviru popolne konkurence in upoštevanje predpostavke o popolni fleksibilnosti cen; (iii) omejena vloga denarne politike. Kot odgovor na omenjene kritike so začeli nastajati t. i. Novo Keynesianski modeli. Zanje je značilno, da so prevzeli nekatere elemente RBC modelov, uvedli pa so tudi nekatere nove, predvsem tiste, ki so značilni za Keynesiansko ekonomiko - zlasti nominalne spremenljivke, nepopolno konkurenco in različne nominalne in realne rigidnosti. V takšnem modelskem okvirju učinki denarne politike niso več nevtralni, kar pomeni, da imajo eksogene spremembe v denarni politiki vpliv tudi na realne kategorije.

Obstajajo številna področja uporabe teh modelov. V pričujoči doktorski disertaciji predstavljam tri izmed njih. V prvem poglavju sem ocenil DSGE model srednjega obsega za slovensko gospodarstvo, ki sem ga uporabil za identifikacijo šokov, ki so bili v ozadju dinamike poslovnega cikla v Sloveniji. V drugem poglavju sem ocenjeni model iz prvega poglavja dopolnil v njegovem fiskalnem delu in ga uporabil za analizo delovanja različnih fiskalnih pravil, in sicer predvsem njihovih stabilizacijskih in blaginjskih učinkov. V tretjem poglavju je ocenjeni DSGE model dopolnjen s šoki v cenah električne energije kot odziv na potrebe enega izmed elektroenergetskih podjetij, saj je model možno uporabiti za ocenjevanje makroekonomskih učinkov sprememb posameznih komponent cen električne energije na ključne ekonomske kategorije, kar med drugim predstavlja osnovo pri sprejemanju številnih odločitev znotraj podjetja (npr. pri načrtovanju omrežij za prenos električne energije, izračunu prihodnjih prihodkov ipd.) (Rhys, 1984).

Poleg uvodnega poglavja, v katerem sem predstavil raziskovalno področje doktorske disertacije,

[68] Dodatne informacije o DSGE modelih so med drugim na voljo v Galí (2008) in Woodford (2003).

je povzetek doktorske disertacije v slovenskem jeziku razdeljen na štiri poglavja. V drugem poglavju sem pozornost namenil predstavitvi raziskovalnega namena in ciljev doktorske disertacije. Temu sledi opis raziskovalnih metod in podatkov. V četrtem poglavju predstavljam glavne ugotovitve doktorske disertacije. Na koncu sledi še predstavitev znanstvenega doprinosa in predstavitev možnosti za nadaljnje raziskovanje.

Raziskovalni namen in cilji doktorske disertacije

Glavni namen doktorske disertacije je ocenjevanje DSGE modela srednjega obsega za Slovenijo in na tej osnovi prikaz njegove uporabe na treh različnih področjih, in sicer na: (i) področju strukturne analize poslovnega cikla, kjer sem ocenil relativni prispevek posameznih strukturnih šokov na rast BDP-ja (in njegovih komponent) v zadnjih nekaj letih, s posebnim poudarkom na obdobjih recesije in kasnejšega okrevanja; (ii) področju fiskalne politike, kjer sem z uporabo ocenjenega modela ovrednotil delovanje petih različnih fiskalnih pravil; (iii) energetskem področju, kjer je bil razvit DSGE model z elektriko kot podporno orodje pri sprejemanju poslovnih odločitev znotraj elektroenergetskega podjetja.

V prvem poglavju doktorske disertacije je predstavljen ocenjen dinamični stohastični model splošnega ravnotežja (DSGE) za slovensko gospodarstvo, ki služi kot osnovno metodološko orodje skozi celotno doktorsko disertacijo. Model, ki gradi na temeljih Novo Keynesianske ekonomike, je osnovan na modelih iz člankov Adolfson et al. (2007) in Masten (2010). Slednji je model iz Adolfson et al. (2007) dopolnil v dveh smereh, in sicer: (i) s prilagoditvijo za majhno odprto gospodarstvo znotraj skupnega denarnega območja in (ii) z dopolnitvijo fiskalnega dela. V okviru prvega poglavja sem najprej ocenil strukturne parametre in šoke omenjenega modela, in sicer z Bayesiansko statistično metodo na podlagi četrtletnih podatkov za Slovenijo v obdobju 1995-2014, kar po meni znanih informacijah predstavlja prvi poskus ocenjevanja DSGE modela srednjega obsega za slovensko gospodarstvo. Poglavje sem nato nadaljeval s prikazom uporabe modela na področju strukturne analize poslovnega cikla. V ta namen sem prikazal historično dekompozicijo gibanja realne rasti slovenskega BDP-ja (in njegovih komponent) v obdobju 1995-2014, s posebnim poudarkom na nedavnih obdobjih recesije in kasnejšega okrevanja.

V drugem poglavju sem uporabil ocenjeni DSGE model iz prvega poglavja in na njegovi osnovi primerjal makroekonomske učinke petih različnih fiskalnih pravil. Prvo proučevano fiskalno pravilo je pravilo uravnoteženega proračuna, ki v vsakem obdobju izenačuje državne izdatke, ki so sestavljeni iz poplačila obresti na pretekli javni dolg $(R_{t-1} - 1) B_t$ in državne potrošnje $P_t^d G_t$, z načrtovanimi prihodki proračuna $\mathbb{E}_{t-1} \{T_t\}$:

$$(R_{t-1} - 1) B_t + P_t^d G_t = \mathbb{E}_{t-1} \{T_t\} - \rho_{ac} AC_{t-1}, \tag{R.1}$$

pri čemer AC_t označuje prilagoditveni račun (angl. *adjustment account*), ki beleži razliko med načrtovanimi $\mathbb{E}_{t-1} \{T_t\}$ in dejanskimi proračunskimi prihodki T_t:

$$AC_t = (1 - \rho_{ac}) AC_{t-1} + \mathbb{E}_{t-1} \{T_t\} - T_t. \tag{R.2}$$

Drugo fiskalno pravilo, ki ga analiziram, je optimalno enostavno fiskalno pravilo (angl. *optimal simple fiscal rule – OSR*), ki povezuje državno potrošnjo $\hat{g}_t$ s preteklim gibanjem državne podtrošnje $\hat{g}_{t-1}$, inflacije $\hat{\pi}^c_{t-1}$, proizvodne vrzeli $\hat{y}_{t-1}$, proračunskega salda $\widetilde{def}_{t-1}$ in javnega dolga $\hat{b}_{t-1}$:

$$\hat{g}_t = \rho_g \hat{g}_{t-1} - \phi_\pi \hat{\pi}^c_{t-1} - \phi_y \hat{y}_{t-1} - \phi_d \widetilde{def}_{t-1} - \phi_b \hat{b}_{t-1} + \varepsilon_{g,t}. \tag{R.3}$$

Vrednosti koeficientov $\phi_i, i \in \{g, \pi, y, d, b\}$ v fiskalnem pravilu sem določil na podlagi minimizacije funkcije izgube (angl. *loss function*), ki je sestavljena iz dveh členov, in sicer variance inflacije in variance proizvodne vrzeli:

$$\mathbb{E}_t \left[\mathbb{L}_t\right] = \lambda_\pi \text{var}\left[p^c_t - p^c_{t-1}\right] + \lambda_y \text{var}\left[y_t - \bar{y}_t\right]. \tag{R.4}$$

Za razliko od centralne banke predpostavljam, da fiskalna oblast namenja večjo pozornost stabilizaciji proizvodnje vrzeli, zato le-ta vstopa v funkcijo izgube z relativno višjo utežjo. Omenjena funkcija izgube obenem služi tudi za medsebojno primerjavo obravnavanih fiskalnih pravil glede njihove uspešnosti z vidika makroekonomske stabilizacije. Tretje proučevano fiskalno pravilo je pravilo strukturnega salda (angl. *structural budget rule – SBR*), ki ga lahko definiram na naslednji način:

$$\begin{aligned} d^*_t &= d_t + \mathbb{E}_{t-1}\left\{t_t\right\} - tr_t \\ &= g_t + \left(R_{t-1} - 1\right) \frac{b_{t-1}}{\pi^d_t \mu_{z,t}}. \end{aligned} \tag{R.5}$$

V nadaljevanju predpostavljam, da strukturni saldo sledi naslednjemu fiskalnemu pravilu (Bilbiie et al., 2008):

$$\tilde{d}^*_{y,t} = \phi_d \tilde{d}^*_{y,t-1} + \phi_b \hat{b}_{y,t-1}, \tag{R.6}$$

kjer je ϕ_d avtokorelacijski parameter, medtem ko parameter ϕ_b odraža odziv strukturnega salda na gibanje javnega dolga. Kot četrto fiskalno pravilo analiziram pravilo dolžniške zavore (angl. *debt brake rule – DBR*). Značilnost tega pravila je, da določa najvišjo dovoljeno mejo državnih izdatkov na podlagi gibanja trendnih prihodkov z_t:

$$\left(R_{t-1} - 1\right) B_t + P^d_t G_t = z_t - \rho_{ac} AC_{t-1}. \tag{R.7}$$

V tem primeru je prilagoditveni račun definiran kot:

$$AC_t = \left(1 - \rho_{ac}\right) AC_{t-1} + z_t - T_t. \tag{R.8}$$

Zadnje analizirano fiskalno pravilo je optimlno pravilo dolžniške zavore (angl. *optimal debt brake rule – OptDBR*), na podlagi katerega se državni izdatki odzivajo na pričakovano gibanje proizvodne vrzeli $\mathbb{E}_{t-1}\left\{\left(\frac{\bar{Y}_t}{Y_t}\right)^{\sigma_G}\right\}$, kar lahko zapišem kot:

$$\left(R_{t-1} - 1\right) B_t + P^d_t G_t = z_t \mathbb{E}_{t-1}\left\{\left(\frac{\bar{Y}_t}{Y_t}\right)^{\sigma_G}\right\} - \rho_{ac} AC_{t-1} \tag{R.9}$$

in

$$AC_t = \left(1 - \rho_{ac}\right) AC_{t-1} + z_t \mathbb{E}_{t-1}\left\{\left(\frac{\bar{Y}_t}{Y_t}\right)^{\sigma_G}\right\}, \tag{R.10}$$

pri čemer vrednost koeficienta σ_G, ki je tudi v tem primeru določena na podlagi minimizacije funkcije izgube, odraža stopnjo proticikličnosti fiskalne politike.

Tretje poglavje doktorske disertacije odgovarja potrebam gospodarstva, saj je v njem predstavljen model, ki naj bi služil kot podpora poslovnim odločitvam v elektroenergetskem podjetju. Električna energija namreč velja za eno izmed najpomembnejših oblik energije. Prav zaradi njene pomembne vloge pri delovanju gospodarstva in življenju prebivalcev sprememba njene cene postavlja vprašanje makroekonomskih in mikroekonomskih posledic. Za potrebe zagotovitve učinkovitega prenosa električne energije po prenosnem omrežju je poznavanje občutljivosti cene električne energije, kot tudi makroekonomskih in nekaterih mikroekonomskih kategorij na posamezne stroškovne komponente strateškega pomena. V okviru tretjega poglavja je bil razvit DSGE model, v katerega je vključena električna energija na strani potrošnje kot tudi proizvodni dejavnik na strani proizvodnje. Parametri modela so delno ocenjeni na slovenskih makroekonomskih podatkih za obdobje 1995-2014, delno pa kalibrirani na podlagi podatkov za slovenski trg električne energije. Z modelom je možno analizirati makroekonomske posledice sprememb posameznih komponent cene električne energije: grosistične cene, nadomestil za uporabo omrežja, prispevkov, ki jih določata Vlada RS in Agencija za energijo, ter trošarin. Poleg vpliva na ključne komponente bruto domačega proizvoda, model dopušča tudi simulacijo vpliva na prihodke državnega proračuna, kot tudi simulacijo vpliva sprememb cen na gospodinjski in poslovni odjem elektrike. V okviru poglavja je predstavljen model in možnost njegove uporabe v praksi.

Doktorska disertacija odgovarja na naslednja glavna raziskovalna vprašanja:

- Kakšne so ocene strukturnih parametrov in šokov za slovensko gospodarstvo?
- Kateri šoki so bili v ozadju poslovnega cikla v Sloveniji, s poudarkom na obdobjih recesije?
- Katere so podobnosti in razlike med recesijo 2008-2009 in 2013-2013 v smislu vpliva strukturnih šokov?
- Kateri strukturni šoki so najbolj prispevali k okrevanju gospodarske aktivnosti po letu 2013?
- Kakšna je stabilizacijska vloga različnih fiskalnih pravil?
- Katero fiskalno pravilo je boljše z vidika maksimizacije blaginje?
- Kakšno bi bilo preteklo gibanje ključnih makroekonomskih spremenljivk, če bi Slovenija sledila zgoraj predstavljenim fiskalnim pravilom?
- Kakšni so učinki šokov v cenah električne energije na slovensko gospodarstvo?

Raziskovalni cilji doktorske disertacije izhajajo iz raziskovalnih namenov in se nanašajo na korake, ki jih je potrebno izvesti za dosego ciljev. Glavni raziskovalni cilj te disertacije je uporabiti srednje velik DSGE model v skladu z Adolfson et al. (2007) in Masten (2010) ter ga oceniti na slovenskih podatkih. Toda preden se lahko ocenjevanje začne, je potrebno model implementirati v Dynare-u, kar je tudi pomemben cilj, ki je potreben za dosego raziskovalnega namena.

V povezavi z glavnim raziskovalnim ciljem so dodatni raziskovalni cilji naslednji. Za namene drugega poglavja je osnovni model dopolnjen z več fiskalnimi značilnostmi, med katerimi je najpomembnejša vpeljava in modeliranje fiskalnih pravil. V tretjem poglavju sta struktura modela in njegovo ustaljeno stanje prilagojena z elementi cen električne energije. Drugi cilj tretjega poglavja je zbiranje in priprava podatkov, potrebnih za kalibracijo parametrov, povezanih z električno energijo. To je eden izmed ključnih korakov k temu, da bo model uporaben pri izvajanju zanesljivih simulacij.

Opis raziskovalnih metod in podatkov

Metodologija doktorske disertacije temelji na uporabi dinamičnega stohastičnega modela splošnega ravnotežja. Kot izhaja iz njihovega imena, so tovrstni modeli: dinamični (angl. *Dynamic*), kar pomeni, da so odločitve ekonomskih subjektov povezane skozi čas; stohastični (angl. *Stochastic*), saj dovoljujejo naključna gibanja v gospodarstvu kot posledico različnih šokov; poleg tega pa modeli tvorijo splošno ravnotežje (angl. *General Equilibrium*), kar pomeni, da optimalne mikroekonomske odločitve ekonomskih subjektov (t.i. parcialna ravnotežja) povezujejo v splošno ravnotežje. Model sem ocenil z Bayesiansko statistično metodo, kot v članku Adolfson et al. (2007), kar je standardni prostop za ocenjevanje DSGE modelov. Značilnost te metode, ki temelji na Bayesovem teoremu, je, da pri ocenjevanju strukturnih parametrov in šokov modela upošteva tako posameznikova prepričanja o vrednostih ocenjevanih parametrov, kot tudi informacije vsebovane v podatkih, in tako omogoča oceno posteriornih porazdelitev parametrov. V nadaljevanju sledi kratka predstavitev metode, ki jo povzemam po An & Schorfheide (2007). Bayesov teorem lahko zapišem na naslednji način:

$$p\left(\theta|Y_t^{obs}\right) = \frac{p\left(\theta, Y_t^{obs}\right)}{p\left(Y_t^{obs}\right)} \tag{R.11}$$

in

$$p\left(Y_t^{obs}|\theta\right) = \frac{p\left(\theta, Y_t^{obs}\right)}{p\left(\theta\right)}, \tag{R.12}$$

kjer je $p\left(\theta|Y_t^{obs}\right)$ pogojna porazdelitev parametrov (posteriorna porazdelitev), $p\left(\theta, Y_t^{obs}\right)$ je skupna porazdelitev parametrov in podatkov, $p\left(Y_t^{obs}|\theta\right)$ je pogojna porazdelitev podatkov (funkcija verjetja), $p\left(\theta\right)$ je nepogojna porazdelitev parametrov (priorna porazdelitev) in $p\left(Y_t^{obs}\right)$ je mejna porazdelitev podatkov, ki je določena kot:

$$p\left(Y_t^{obs}\right) = \int p\left(\theta, Y_t^{obs}\right) \mathrm{d}\theta = \int p\left(Y_t^{obs}|\theta\right) p\left(\theta\right) \mathrm{d}\theta. \tag{R.13}$$

Ob združitvi enačb (R.11) in (R.12) dobim:

$$p\left(\theta|Y_t^{obs}\right) = \frac{p\left(Y_t^{obs}|\theta\right) p\left(\theta\right)}{p\left(Y_t^{obs}\right)}. \tag{R.14}$$

Enačbo (R.14) lahko v nadaljevanju zapišem kot:

$$p\left(\theta|Y_t^{obs}\right) \propto p\left(Y_t^{obs}|\theta\right) p\left(\theta\right) = K\left(\theta|Y_t^{obs}\right), \tag{R.15}$$

kjer je $K\left(\theta|Y_t^{obs}\right)$ posteriorna gostota, ki je proporcionalna posteriorni porazdelitvi za faktor $p\left(Y_t^{obs}\right)$. Ob logaritmiranju enačbe (1R.15) dobimo:

$$\ln K\left(\theta|Y_t^{obs}\right) = \ln p\left(Y_t^{obs}|\theta\right) + \ln p\left(\theta\right) = L\left(Y_t^{obs}|\theta\right) + \ln p\left(\theta\right), \tag{R.16}$$

kar je ključna enačba v okviru Bayesianskega ocenjevanja. Priorne porazdelitve ocenjevanih parametrov in šokov sem določil v skladu z običajnimi porazdelitvami, ki se uporabljajo v literaturi, kot na primer v Adolfson et al. (2007), Smets, & Wouters (2003, 2007) in Fernández-Villaverde (2010). Za oceno funkcije verjetja, ki predstavlja skupno porazdelitev vseh opazljivih spremenljivk, pogojno glede na strukturo in parametre modela, sem uporabil Kalmanov filter, pod predpostavko, da se strukturni šoki modela porazdeljujejo normalno. Skupno posteriorno porazdelitev ocenjevanih parametrov in šokov modela sem nato simuliral s pomočjo metode Monte Carlo markovskih verig, in sicer z uporabo Metropolis-Hastingsovega algoritma.

Ocene modela temeljijo na slovenskih četrtletnih podatkih za obdobje 1995-2014. Pri ocenjevanju sem uporabil naslednje časovne serije: BDP, potrošnjo, investicije, državno potrošnjo, izvoz in uvoz, realni efektivni devizni tečaj, bruto plače (dohodkovna struktura BDP), zaposlenost (domači koncept), BDP deflator, domačo posojilno obrestno mero, CPI inflacijo, tuji BDP, tuji BDP deflator in 12-mesečni Euribor, pri čemer se tuje časovne serije nanašajo na prvih 12 držav članic Evro območja. Časovne serije smo pridobili iz podatkovnih baz in publikacij Evropskega statističnega urada (EUROSTAT), Statističnega urada RS (SURS) in Banke Slovenije (BS).

V drugem poglavju doktorske disertacije, v katerem sem primerjal makroekonomske učinke fiskalnih pravil, sem uporabil DSGE model iz prvega poglavja, ki sem ga prilagodil v njegovem fiskalnem delu, kjer izstopa predvsem vpeljava in modeliranje fiskalnih pravil. Primerjava fiskalnih pravil je potekala v več korakih. Najprej sem ocenil DSGE model na podlagi makroekonomskih podatkov za Slovenijo za obdobje od 1995Q1 do 2014Q4. Ker Slovenija v tem obdobju ni imela v veljavi nobenega posebnega fiskalnega pravila, sem za državno potrošnjo predpostavil, da sledi enostavnemu AR(1) procesu. Po končanem postopku ocenjevanja sem fiskalna pravila ovrednotil na tri načine: prvič, s pomočjo analize impulznih odzivov. Drugič, primerjal sem makroekonomsko volatilnost ključnih makroekonomskih spremenljivk pod vsakim fiskalnim pravilom. V tem primeru sem postopal takole: Najprej sem iz normalne porazdelitve generiral časovne serije modelskih strukturnih šokov z dolžino 200, pri čemer sem standardni odklon porazdelitve postavil na posteriorno sredino. Generirane časovne serije strukturnih šokov sem nato uporabil za simulacijo štirih izbranih spremenljivk: rasti proizvoda, rasti državne potrošnje, proračunskega salda in javnega dolga, pri čemer sem AR(1) proces v osnovnem DSGE modelu nadomestil s fiskalnim pravilom. Postopek sem ponovil 10000-krat. V vsaki izvedeni simulaciji sem izračunal standardni odklon prej omenjenih štirih spremenljivk, tako da sem dobil 10000 standardnih odklonov za vsako spremenljivko. Nazadnje sem izračunal povprečni standardni odklon za vsako izmed proučevanih spremenljivk. Na koncu sem izvedel še protidejstveni eksperiment (angl. *counter-factual experiment*), s katerim sem želel ugotoviti, kakšno bi bilo preteklo gibanje prej omenjenih spremenljivk, če bi bila v veljavi proučevana fiskalna pravila.

Tretje poglavje prav tako nadaljuje z uporabo DSGE model iz prvega poglavja, ki je bil prilagojen z električno energijo, ki je vključena tako na strani potrošnje kot tudi na strani proizvodnje. Za potrebe simulacij modela je v okviru poglavja posebna pozornost namenjena kalibraciji parametrov, ki so povezani z električno energijo. Postopek njihove kalibracije je predstavljen v nadaljevanju.

Kalibracija ravnovesnih deležev. Najprej je bilo potrebno kalibrirati ravnovesne deleže. Za potrebe modela je bilo potrebno določiti delež stroškov, ki ga elektrika predstavlja v celotni dodani vrednosti gospodarstva. V ta namen so bili uporabljeni AJPES-ovi podatki iz bilanc podjetij, ki vsebujejo informacijo o stroških energije. Iz teh podatkov izhaja, da je delež energije v dodani vrednosti podjetij v obdobju 2002-2012 znašal 9.8 %. Ta delež je v celotnem obdobju naraščal in je v letu 2012 dosegel 12.4 %. Pri tem je potrebno opozoriti, da so to stroški povezani z vsemi energenti, elektrika pa pri tem predstavlja le del. Ta delež znaša približno polovico oz. 6 % dodane vrednosti. Na strani povpraševanja je bilo potrebno določiti delež električne energije v končni potrošni košarici. Po podatkih Statističnega urada RS je ta delež v letu 2013 znašal 3.8 %. Za potrebe simulacij modela je bilo potrebno določiti tudi delež gospodinjskega odjema in delež doma proizvedene elektrike. Prvi parameter zavzema vrednost 0.33, vrednost drugega parametra pa je postavljena na 0.7.

Kalibracija cenovnih elastičnosti ponudbe in povpraševanja. Posebna pozornost je namenjena specifikaciji ponudbe električne energije. DSGE model je namenjen kratkoročni in srednjeročni ekonomksi analizi, torej za pojasnjevanje makroekonomske dinamike na frekvenci poslovnega cikla. Glede proizvodnih kapacitet elektrike je predpostavljeno, da so le-te na frekvenci poslovnega cikla dane in dovolj visoke, da se popolnoma prilagodijo nihanjem v povpraševanju. To je možno utemeljiti na tri načine. Prvi način je narava investicij v produkcijo elektrike. Te so obsežne, planirane dolgo v naprej, njihova implentacija traja daljše časovno obdobje, spremembe pa so podvržene presoji držžvnih organov. Drugič, Slovenija je del sproščenega evropskega trga, na mejah pa so inštalirane zadostne prenosne zmogljivosti, da elektrika iz uvoza zadosti nihanjem v povpraševanju ob danih borznih cenah v tujini. Pri tem večina uvožene električne energije prihaja preko avstrijske meje. Fizični delež uvožene električne energije je parameter, ki ga je potrebno v modelu kalibrirati, čeprav nima bistvenega vpliva na makroekonomsko dinamiko. V preteklosti se je delež domače porabe elektrike, ki se je zadostil z uvozom, gibal okrog ene tretjine. Za domačo proizvodnjo elektrike je predpostavljeno, da je, upoštevaje lastno ceno, popolnoma elastična v določenem cenovnem rangu, ki vključuje vklop v omrežje generacijske kapacitete. To pomeni, na primer, da je pri nižjih cenovnih rangih polno aktivna ponudba hidroelektrarn in jedrske elektrarne, pri višjih cenovnih rangih pa se močneje aktivirajo termo proizvodne kapacitete. Upravičeno je mogoče predpostaviti, da lahko uporabnik modela ob poznavanju proizvodnih kapacitet dovolj natančno predvidi delež celotne proizvodnje električne energije v določenem cenovnem pasu in ga določi kot pripadajoči parameter modela. V modelu so dohodkovne elastičnosti povpraševanja po električni energiji določene na podlagi strukturnih povezav v modelu. Te pomenijo, kot je razvidno iz simulacij modela, da povpraševanje po električni energiji v veliki meri niha z nihanjem ekonomske aktivnosti. Na kratek rok korelacija ni popolna, na dolgi rok pa obstaja visoka stopnja soodvisnosti. Cenovna elastičnost povpraševanja pa je kalibrirana s pomočjo študije Liu (2004), ki vsebuje ocene elastičnosti povpraševanja za OECD države. V študiji je ocena kratkoročne elastičnosti povpraševanja gospodinjstev -0.03. Kratkoročna elastičnost povpraševanja podjetij pa je nižja in znaša -0.015. Iz obeh ocen izhaja, da je povpraševanje po električni energiji cenovno neelastično.

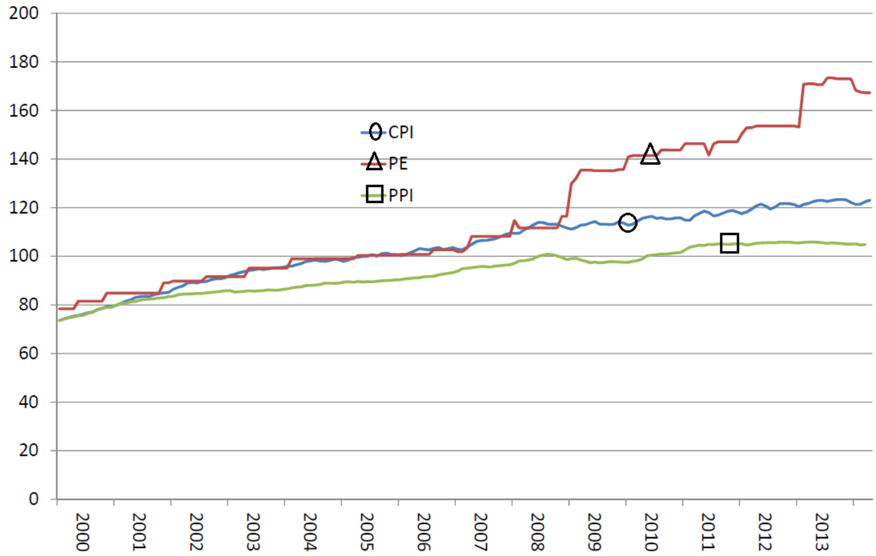
Kalibracija strukture cene elektrike. Maloprodajna cena električne energije je sestavljena iz cene energije (grosistična cena), ki ji je potrebno dodati še nadomestilo za uporabo omrežja, različne prispevke, trošarino in davek na dodano vrednost. Davek na dodano vrednost je proporcionalen in ne predstavlja izziva. Ostale komponente pa so izražene na enoto porabljene energije v fiksnem znesku, zato je potrebno v modelu kalibrirati njihove deleže v končni maloprodajni ceni (pred DDV). Za potrebe razvoja modela so uporabljeni podatki iz leta 2012. Na domačo grosistično ceno energije vpliva tudi strošek čezmejnih prenosnih zmogljivosti (ČPZ). Vpliv tega stroška na tržno ceno ni določen znotraj modela, temveč je predvideno, da to določi uporabnik kot vhodni podatek pri simulaciji modela.

Parameterizacija procesa cen električne energije. V modelu je bilo potrebno določiti tudi enačbe določanja cen grosistične cene energije. Ker historične časovne serije grosističnih cen elektrike niso na voljo na visoki frekvenci (vsaj kvartalni), so bile pri analizi lastnosti procesa cen uporabljene maloprodajne cene. Slika (R.1) prikazuje gibanje indeksa cen življenjskih potrebščin (CPI), indeksa cen proizvajalcev (PPI) in indeksa maloprodajnih cen elektrike (PE). Iz slike je razvidno, da je divergenca cen v veliki meri zaznamovana z znatnimi skoki cen elektrike, ki so posledica skokov v prispevkih (januar 2009 in februar 2013). Tovrstni skoki so predvidljivi, saj so ponavadi eksplicitno napovedani bodisi s strani RS ali Agencije za energijo RS. Iz Slike (R.2) je razvidno, da diskretni skoki cene elektrike povzročijo tudi trajne oz. vztrajne spremembe relativnih cen elektrike, tj. cene elektrike glede na splošne cene življenjskih potrebščin ali pa glede na cene proizvajalcev. Da bi se zajelo empirične regularnosti pri modeliranju cen, je bil ocenjen naslednji model:

$$\pi_t^{e,c} = \alpha_e \pi_{t-1}^{e,c} - \alpha_\gamma \gamma_{t-1}^{ec,d} + \varepsilon_t^{ec,d}, \tag{R.17}$$

pri čemer $\pi_t^{e,c}$ predstavlja mesečno stopnjo rasti cen električne energije za gospodinjstva, kot jo spremlja SURS, $\gamma_{t-1}^{ec,d} \equiv \ln\left(P_t^{e,c}\right) - \ln\left(P_t^d\right)$ pa je logaritem relativne cene elektrike glede na indeks cen proizvajalcev (P_t^d). Tovrsten proces je v modelu predpostavljen tako za cene elektrike za gospodinjstva kot tudi za podjetja (v nadaljevanju jih označujem s $P_t^{e,d}$), kar je smiselno glede na dejstvo, da je večina kratkoročne variacije v cenah posledica sprememb grosistične cene energije.

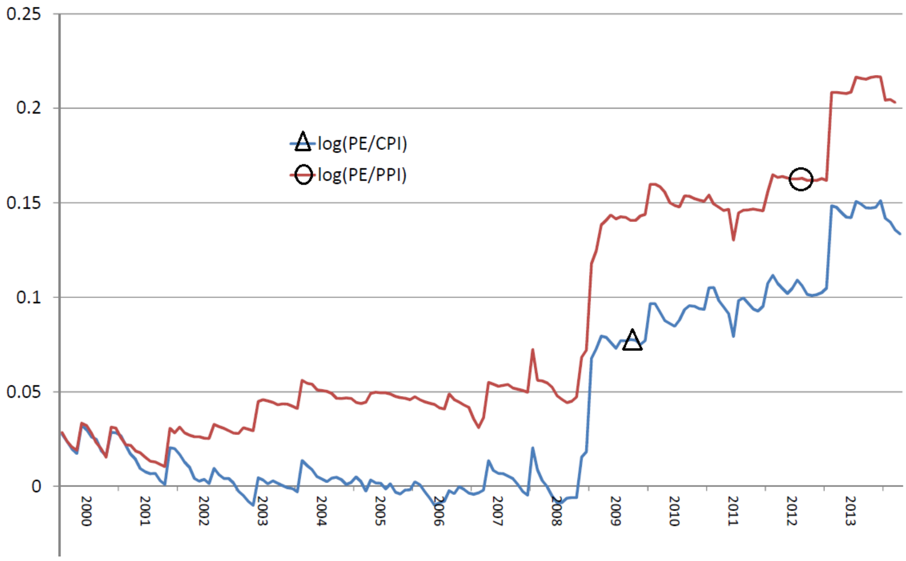
Figure R.1: *Zgodovinske cene elektrike za gospodinjstva (PE), indeks cen življenjskih potrebščin (CPI) in indeks cen proizvajalcev (PPI)*



Vir: SiStat podatkovna baza.

Model (R.17) je enostaven model korekcije napak. Za inflacijo cen elektrike je predpostavljeno, da sledi avtoregresijskemu procesu, ki se do določene mere (preko koeficienta α_γ) prilagaja tudi odklonom teh cen od ostalih cen v gospodarstvu. Na ta način je zajeto dejstvo nizke, a vendar prisotne elastičnosti substitucije med elektriko in ostalimi dobrinami v gospodarstvu. Model je ocenjen na podlagi mesečnih podatkov za obdobje januar 2000-marec 2014, in sicer z metodo navadnih najmanjših kvadratov (OLS), ki zagotavlja konsistentne ocene parametrov ob pogoju, da napake modela $\varepsilon_t^{ec,d}$ niso avtokorelirane. To se tudi izkaže z uporabo klasičnega *LM* testa avtokorelacije ostankov modela, saj za test avtokorelacije 4. reda p vrednost testa znaša 0.21. Ocene parametrov modela so naslednje. Ocena parametra α_e je -0.02 in statistično neznačilno različna od nič. Ocena parametra α_γ pa znaša -0.01 in je značilna pri 10 % stopnji tveganja.

Figure R.2: *Gibanje relativnih cen elektrike za gospodinjstva*



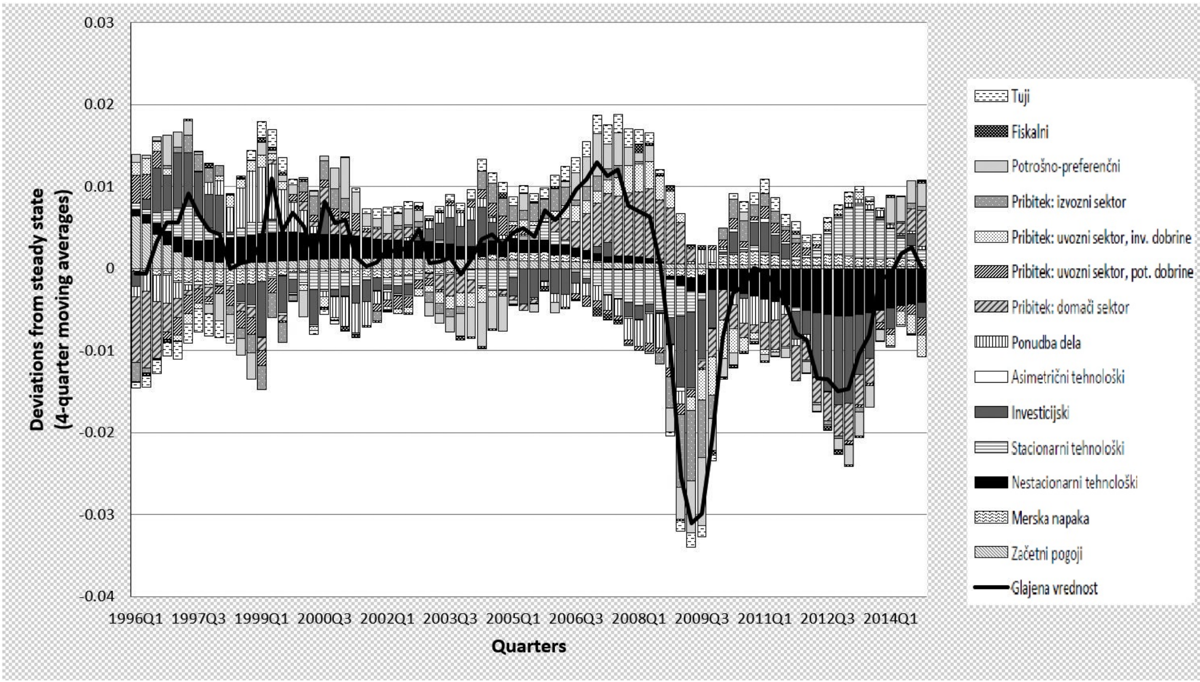
Vir: SiStat podatkovna baza.

Povzetek glavnih ugotovitev doktorske disertacije

V tem poglavju povzemam glavne ugotovitve doktorske disertacije.

Prvo poglavje doktorske disertacije je bilo namenjeno ocenjevanju DSGE modela srednjega obsega za Slovenijo in na tej osnovi prikazu historične dekompozicije gibanja realne rasti BDP-ja in njegovih komponent, s posebnim poudarkom na obdobjih nedavne recesije. Rezultati, ki so predstavljeni na Sliki (R.3), kažejo, da so v obdobju prve recesije (2008-2009) glavni dejavnik negativne gospodarske rasti predstavljali investicijski šoki, ki so se odražali v padcu investicij, ki je nastal zaradi manjših tujih in domačih naročil kot tudi povečane negotovosti glede prihodnjih ekonomskih obetov. Pomemben negativen vpliv na gospodarsko rast so imeli tudi potrošno-preferenčni šoki in šoki v pribitkih izvoznega sektorja, kar lahko v prvem primeru povezujem z zmanjšanjem dohodkov gospodinsjtev (v povezavi s povečanim previdnostnim varčevanjem), v drugem primeru pa s padcem izvoznega povpraševanja kot posledica zmanjšane zunanje konkurenčnosti gospodarstva, ki je nastala predvsem zaradi hitrejše rasti plač od rasti produktivnosti v obdobju pred krizo. Nadalje rezultati kažejo, da so imeli fiskalni šoki sprva pozitiven vpliv na gospodarsko aktivnost, vendar pa se je že v letu 2010 zgodil preobrat, saj so bili sprejeti številni varčevalni ukrepi za konsolidacijo javnih financ. Na gospodarsko rast so negativno vplivali tudi permanentni tehnološki šoki, ki jih lahko povezujem predvsem z odsotnostjo ustreznih strukturnih reform v času pred začetkom krize. Po drugi strani pa so imeli stacionarni tehnološki šoki pozitiven vpliv na gospodarsko rast, posebej v času druge recesije, kar lahko odraža težnjo podjetij po sprejemanju ukrepov za izboljšanje svojega konkurenčnega položaja. Nazadnje rezultati kažejo, da je okrevanje gospodarske aktivnosti na koncu proučevanega obdobja izhajalo predvsem iz pozitivnega vpliva potrošno-preferenčnih šokov, ki jih lahko povezujem z večjim zaupanjem potrošnikov, izvedeno sanacijo bančnega sistema in izboljševanjem razmer na trgu dela.

Figure R.3: *Historična dekompozicija gibanja rasti BDP-ja v enotah strukturnih šokov*



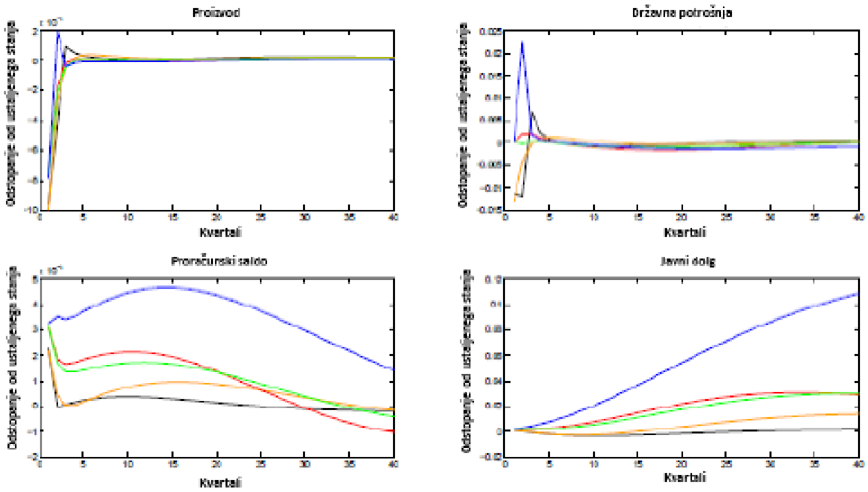
Opomba: Glajena časovna serija je prikazana z odstranjeno sredino.

Vir: Lasten prikaz.

Iz rezultatov historične dekompozicije izhajajo tudi nekatera priporočila za vodenje ekonomske politike. Za oblikovalce ekonomskih politik je pomembno, da poznajo, kakšno vlogo v poslovnem ciklu imajo različni šoki, da lahko ocenijo potencialni uspeh preteklih sprejetih ukrepov ekonomske politike. Hkrati lahko rezultati služijo tudi kot podlaga za oblikovanje prihodnjih ukrepov. Izstopata predvsem dva rezultata. Prvi je povezan s preteklimi sprejetimi ukrepi, ki se nanašajo na reševanje bančnega sistema. Svetovna gospodarska kriza je močno prizadela slovenski bančni sistem. Zaradi prekomernega posojanja in velikega padca gospodarske aktivnosti se je v bilancah bank nabrala znatna količina slabih posojil. Zato je bilo v letu 2013 sprejetih več ukrepov za stabilizacijo bančnega sistema. V letu 2014, ki je leto po izvedeni sanaciji bank, rezultati historične dekompozicije rasti BDP kažejo, da je bil pomemben pozitiven učinek povezan z investicijskimi šoki, zaradi katerih se je povečala nagnjenost k naložbam. To je nedvomno posledica povečanega zaupanja v zasebnem sektorju, ki ga je možno pripisati reševanju težav v bančnem sistemu. Druga pomembna ugotovitev je, da so negativni učinki potrošno-preferenčnih šokov v letu 2014 popolnoma izginili. Gre za posledico, ki izhaja iz povečanega zaupanja potrošnikov, kar je prav tako možno pripisati reševanju bank, saj je bilo s tem odpravljeno tveganje plačilne sposobnosti, posledično pa se je zmanjšala negotovost glede prihodnjih dohodkov. Na področju prihodnjih ukrepov bi morala Slovenija pospešiti izvajanje strukturnih reform, saj so učinkovite in dobro zasnovane strukturne reforme ključne za povečanje konkurenčnosti in potenciala rasti gospodarstva ter lahko prispevajo k večji vključenosti te rasti. Priporočilo izhaja neposredno iz rezultatov historične dekompozicije. Razvidno je, da so permanentni tehnološki šoki, za katere bi lahko veljalo, da so tesno povezani s strukturnimi reformami, v zadnjih letih pretežno negativno vplivali na rast BDP, kar jasno kaže, da se je hitrost izvajanja strukturnih reform upočasnila. Slovenija se trenutno sooča z več izzivi, verjetno najpomembnejši so tisti, ki se nanašajo na staranje prebivalstva in pomanjkanje delovne sile. Zato bi bilo potrebno v bližnji prihodnosti izvesti reforme na področju trga dela, reforme izobraževalnega sistema in sprejeti ustrezne ukrepe migracijske politike. Tudi druge reforme, kot so tiste, osredotočene na širše poslovno okolje in obdavčenje, bi bile prav tako potrebne.

Drugo poglavje doktorske disertacije je bilo namenjeno analizi makroekonomskih učinkov petih fiskalnih pravil v okviru ocenjenega DSGE modela iz prvega poglavja. V prvem delu drugega poglavja sem najprej primerjal lastnosti fiskalnih pravil preko analize impulznih odzivov ključnih makroekonomskih spremenljivk: rasti proizvoda, rasti državne potrošnje, proračunskega salda in javnega dolga na primeru negativnega investicijskega šoka. Rezultati ocenjevanja in historične dekompozicije iz prvega poglavja doktorske disertacije so namreč pokazali, da je bil investicijski šok najpomembnejši dejavnik negativne gospodarske rasti v Sloveniji v obdobju zadnjih dveh recesij. Iz rezultatov impulznih odzivov, ki so prikazani na Sliki (R.4), izhaja, da bi ob negativnem investicijskem šoku prišlo do krčenja državne potrošnje, v kolikor bi bilo v veljavi BBR pravilo, kar bi še dodatno okrepilo negativni vpliv investicijskega šoka na rast proizvoda. Na drugi strani pa bi ob veljavi DBR in OptDBR pravila prišlo do povečanja javne porabe, kar bi pomenilo manjše negativne posledice investicijskega šoka na rast proizvoda. Gre za proticiklični ukrep, ki zahteva večjo porabo, ko je gospodarstvo v recesiji, in obratno. Kot kažejo rezultati, je največje povečanje državne potrošnje doseženo po dveh četrtletjih, in sicer v okviru OptDBR pravila, medtem ko je povečanje pod OSR pravilom manjše. Nadalje je razvidno, da se pod DBR pravilom državna potrošnja ne odziva na negativni investicijski šok, kar je v skladu z osnovno idejo tega pravila. Nasprotno pa BBR in SBR pravili zahtevata manjšo državno porabo, kar je posledica padca davčnih prihodkov v primeru BBR pravila in višjega primanjkljaja v primeru SBR pravila. Kar se tiče vpliva na rast proizvoda je učinek šoka najbolj negativen pod BBR in SBR praviloma, medtem ko je najmanjši negativni učinek dosežen pod OptDBR pravilom. Odziv pod OSR in DBR praviloma pa leži nekje vmes, pri čemer sta si njuna odziva zelo podobna. Glede vpliva na javne finance so rezultati naslednji. OptDBR pravilo vodi do največjega povečanja proračunskega primanjkljaja med vsemi obravnavanimi fiskalnimi pravili, medtem ko ima pri ostalih fiskalnih pravilih negativni investicijski šok opazno manjši učinek na proračunski primanjkljaj. Primerjava med OSR in DBR praviloma kaže, da je dinamika proračunskega primanjkljaja v prvih petih letih po šoku nekoliko večja pod OSR pravilom, nato pa se hitro vrne k ustaljenemu stanju, medtem ko je učinek na primanjkljaj pod DBR pravilom bolj persistenten. Podobni so tudi rezultati v primeru odziva javnega dolga.

Figure R.4: *Impulzni odzivi nekaterih ključnih spremenljivk na negativni investicijski šok pod različnimi fiskalnimi pravili*



Legenda: črna: BBR, oranžna: SBR, rdeča: OSR, zelena: DBR, modra: OptDBR.

Vir: Lasten prikaz.

V nadaljevanju sem primerjal makroekonomsko volatilnost rasti realnega BDP-ja, rasti realne državne potrošnje, proračunskega salda in javnega dolga pod zgoraj predstavljenimi fiskalnimi pravili. Rezultati simulacij, predstavljeni v Tabeli (R.1), kažejo, da BBR pravilo povzroča najvišjo stopnjo volatilnosti rasti proizvoda, kar odraža dejstvo, da je BBR po svoji naravi prociklično fiskalno pravilo, kar pomeni, da ne onemogoča vodenja stabilizacijske politike skozi poslovni cikel. Nadalje iz rezultatov izhaja, da je volatilnost rasti proizvoda pod OSR in OptDBR pravilom bistveno nižja. Takšen rezultat je posledica dejstva, da obe pravili omogočata eksplicitno reakcijo fiskalne politike na gibanje proizvodne vrzeli v smislu proticikličnega odziva, kar pomeni, da v obdobju nizke gospodarske rasti omogočata relativno večje trošenje države, v obdobju visoke gospodarske rasti pa na trošenje delujeta omejevalno. Nadalje rezultati kažejo, da je v primerjavi z OSR in OptDBR pravilom volatilnost rasti proizvoda pod DBR nekoliko višja. Razlog za takšen rezultat izhaja iz dejstva, da je DBR le implicitno proticiklično naravnan. Iz rezultatov tudi izhaja, da vsa proučevana fiskalna pravila omogočajo doseganje nižje volatilnosti rasti državne potrošnje v primerjavi s prockličnim BBR pravilom. V povezavi s tem je možno opaziti, da je volatilnost rasti državne potrošnje najnižja pod OSR pravilom, sledi DBR pravilo, tretje je OptDBR pravilo in zadnje SBR pravilo. Glede stabilizacije proračunskega salda in javnega dolga so rezultati naslednji. Primerjava volatilnosti proračunskega salda pod DBR in OptDBR pravilom kaže, da je nižja volatilnost rasti proizvoda pod OptDBR dosežena na račun višje volatilnosti proračunskega salda, kar je skladno s pričakovanji, saj OptDBR pravilo omogoča vodenje aktivnejše fiskalne politike. Enaka ugotovitev velja za volatilnost javnega dolga. Skladno s pričakovanji je volatilnost proračunskega salda in javnega dolga najnižja pod BBR in SBR pravilom, pri čemer obe pravili izkazujeta podobne rezultate. Nadalje rezultati kažejo, da OSR in DBR pravili dajeta enakovredne rezultate glede stabilizacije javnega dolga. Iz rezultatov simulacij tudi izhaja, da čeprav je volatilnost rasti proizvoda pod OSR in OptDBR praviloma precej primerljiva, je OSR pravilo bolj učinkovito pri stabilizaciji javnega dolga. Takšen rezultat je možno pojasniti z dejstvom, da OSR pravilo omogoča neposreden odziv fiskalne politike na gibanje javnega dolga. Na primer, v času recesije OSR pravilo zahteva povečanje javne porabe. Istočasno pa pride ob nižji gospodarski rasti do zmanjšanja davčnih prihodkov in povečanja socialnih transferjev, zaradi česar se stanje javih financ avtomatično poslabša, kar skladno s fiskalnim pravilom zahteva nižjo javno porabo in posledično vodi do nižje volatilnosti javnega dolga. Nasproten proces se zgodi v obdobju ekspanzije. Vključitev javnega dolga v fiskalno pravilo pomeni izključevanje med višjo volatilnostjo proizvodne vrzeli in nižjo volatilnostjo javnega dolga. Kljub temu menim, da bi moral biti odziv fiskalnih oblasti na javni dolg pomemben sestavni del vsakega fiskalnega pravila, saj se s tem bistveno ne povečuje volatilnost proizvodne vrzeli, obenem pa bi vodenje takšne fiskalne politike omogočalo doseganje občutno nižje volatilnosti javnega dolga.

Table R.1: *Makroekonomska volatilnost okrog ustaljenega stanja (merjena kot standardni odklon) izbranih makroekonomskih agregatov pod različnimi fiskalnimi pravili*

Spremenljivke	BBR	OSR	SBR	DBR	OptDBR
Rast proizvoda	2.99	1.28	1.95	1.84	1.31
Rast državne potrošnje	12.79	2.08	5.38	6.84	4.14
Proračunski saldo	1.07	2.42	1.56	1.97	4.12
Javni dolg	13.65	26.83	15.49	27.65	158.99

Opombe: BBR: Pravilo uravnoteženega proračuna; OSR: Optimalno enostavno fiskalno pravilo; SBR: Pravilo strukturnega salda; DBR: Osnovno pravilo dolžniške zavore; OptDBR: Optimalno pravilo dolžniške zavore

Vir: Lasten prikaz.

V kolikor primerjam proučevana fiskalna pravila z vidika celotne blaginje (glej Tabelo (R.2)), ki je merjena kot seštevek variance proizvodne vrzeli in variance inflacije, lahko ugotovim, da vsa fiskalna pravila omogočajo doseganje višje stopnje blaginje v primerjavi z BBR pravilom. Najvišja stopnja blaginje je dosežena pod OSR pravilom, in sicer za 50 %, sledi OptDBR pravilo, pri katerem je blaginja večja za 49 %, na tretjem mestu je DBR pravilo z izgubo nižjo za 42 %, medtem ko predzadnje mesto zaseda SBR pravilo, pri katerem je izguba nižja za 26 %.

Table R.2: *Nepogojna izguba pod različnimi fiskalnimi pravili ($\lambda_\pi = 0.2$ in $\lambda_y = 1$)*

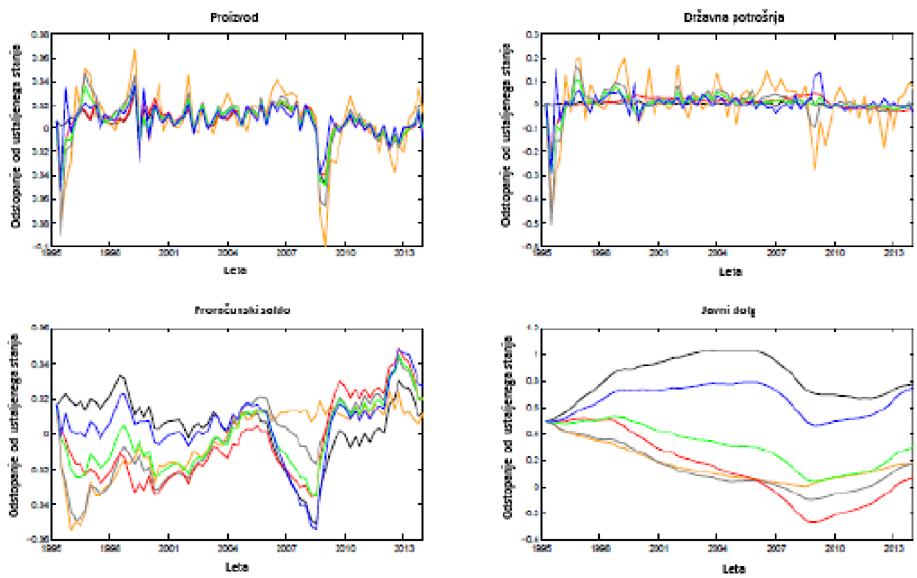
Vrsta fiskalnega pravila	Var (π_t^c)	Var $(y_t - \bar{y}_t)$	$\frac{\mathbb{E}_t[\mathbb{L}_t]^{i \in \{\text{BBR,OSR,SBR,DBR,OptDBR}\}}}{\mathbb{E}_t[\mathbb{L}_t]^{\text{BBR}}}$
BBR	0.52	2.67	1
OSR	0.54	1.28	0.50
SBR	0.52	1.95	0.74
DBR	0.53	1.50	0.58
OptDBR	0.54	1.31	0.51

Opombe: BBR: Pravilo uravnoteženega proračuna; OSR: Optimalno enostavno fiskalno pravilo; SBR: Pravilo strukturnega salda; DBR: Osnovno pravilo dolžniške zavore; OptDBR: Optimalno pravilo dolžniške zavore

Vir: Lasten prikaz.

V zadnjem delu drugega poglavja sem napravil protidejstveni eksperiment (angl. *counterfactual experiment*), s katerim sem želel ugotoviti, kakšno bi bilo gibanje rasti proizvoda, rasti državne potrošnje, proračunskega salda in javnega dolga v preteklosti, če bi Slovenija sledila zgoraj predstavljenim fiskalnim pravilom. Rezultate simulacij prikazuje Slika (R.5). Opaziti je možno, da bi Slovenija dosegala bistveno bolj vzdržno gibanje javnega dolga, kar bi imelo številne pozitivne makroekonomske posledice, kot so nižje obrestne mere, pritok kapitala, optimistična pričakovanja, povečanje ekonomske aktivnosti in nadaljnje izboljšanje javnih financ.

Figure R.5: *Historične (glajene) in simulirane časovne vrste nekaterih ključnih spremenljivk pod različnimi fiskalnimi pravili*



Legenda: črna: glajena serija, oranžna: BBR, siva: SBR, rdeča: OSR, zelena: DBR, modra: OptDBR.

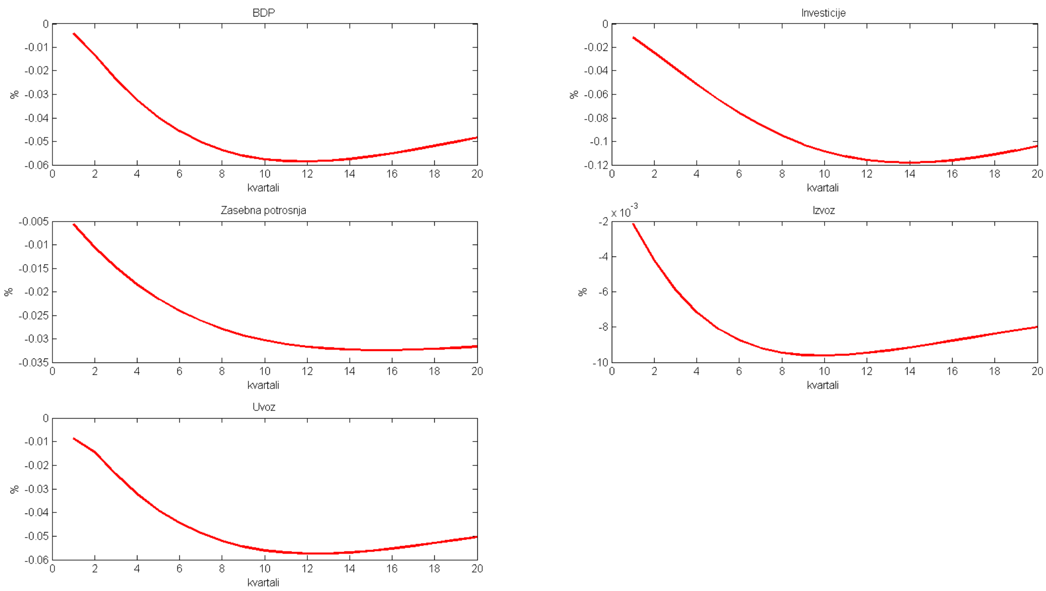
Vir: Lasten prikaz.

Analiza v drugem poglavju kaže, da imajo fiskalna pravila svoje prednosti in pomanjkljivosti. Rezultati simulacij kažejo predvsem na izključevanje med fiskalno stabilizacijo in proticiklično stabilizacijo. Kar zadeva priporočila ekonomski politiki, mora oblikovanje fiskalnih pravil upoštevati tako potrebo po kratkoročni proticiklični stabilizaciji kot tudi zagotoviti dolgoročno fiskalno vzdržnost. To bi bilo možno doseči s kombinacijo različnih fiskalnih pravil, kar je običajna praksa v državah, ki izvajajo fiskalno politiko na podlagi pravil, čeprav bi bila uporaba enega pravila bolj preprosta. Uspeh fiskalnih pravil je povezan tudi z drugimi lastnostmi, kot so preglednost, verodostojnost in enostavnost izvedbe, o katerih se pogosto piše v literaturi. Kar zadeva izvedbeni vidik, nekatera pravila so glede na rezultate DSGE modela boljša pri zagotavljanju najvišje stopnje blaginje, vendar je lahko njihovo izvajanje zahtevno. Tak primer je optimalno fiskalno pravilo, ki glede na dobljene rezultate omogoča najnižje znižanje blaginje, vendar pa je povezano z ocenami proizvodne vrzeli in optimizacijo koeficientov, kar je morda v praksi težje izvedljivo in tudi predstavljeno javnosti. Zato bi bila verjetno boljša izbira pravilo dolžniške zavore, ker se zdi razmeroma enostavno in enostavno razumljivo. Poleg tega to pravilo omogoča doseganje podobne stopnje blaginje in volatilnosti kot bolj zapleteno optimalno fiskalno pravilo, kar je ena izmed pomembnih ugotovitev za vodenje fiskalne politike, ki kaže na to, da za dobro pravilo ni nujno potrebna kompleksnost.

V zadnjem delu tretjega poglavja je prikazana možnost uporabe modela v praksi skozi nekaj možnih hipotetičnih scenarijev. Najprej je predstavljena osnovna simulacija, in sicer učinki 1-odstotnega dviga cen grosistične cene elektrike na makroekonomske spremenljivke. Do tega lahko pride zaradi dviga stroška čezmejnih prenosnih zmogljivosti (ČPZ). Dvig stroška je trajen in povzroči zelo persistenten vpliv na cene, kar pomeni, da je kasnejše endogeno prilagajanje maloprodajnih cen skladno s strukturnimi enačbami modela relativno počasno. Rezultati so prikazani na Slikah (R.6)-(R.8). Gre za prikaz t. i. impulznih odzivov spremenljivk, pri čemer impulz predstavlja eksogeno spremembo cen električne energije (na grosističnem trgu), odzivi pa so spremembe izbranih spremenljivk modela, ki impulzu sledijo. Na Sliki (R.6) so prikazani odzivi osnovnih makreokonomskih agregatov, od bruto domačega proizvoda do uvoza. Na Sliki (R.7) so prikazani odzivi prihodkov proračuna in proračunskega dečita, na Sliki (R.8) pa odzivi odjema električne energije, inflacije, realnih mejnih stroškov gospodarstva in stopnje rasti maloprodajnih cen elektrike. Analiza impulznih odzivov pokaže naslednje. Elektrika je pomemben proizvodni dejavnik in potrošna dobrina v gospodarstvu, kar pomeni, da njena podražitev podraži tako končne cene kot tudi poveča stroške gospodarstva (glej odziv mejnih stroškov v Sliki (R.8)). Zato eksogeni dvigi cen delujejo stagflacijsko na gospodarstvo. Istočasno je možno opaziti kratkotrajno povečanje inflacije za približno 0.02 o. t. (Slika (R.8)) in znižanje ekonomske aktivnosti (Slika (R.6)). Znižanje bruto domačega proizvoda, pri čemer je potrebno to znižanje razumeti kot odlon od trendne rasti, doseže vrh pri skoraj 0.06 o. t. 3 leta po začetni spremembi cen in se nato le počasi vrača nazaj k ravnovesju. Na investicije je učinek nekoliko močnejši (znižanje za 0.12 o. t.), blažji pa na zasebno potrošnjo. Po dveh letih in pol se za skoraj 0.01 o. t. zniža izvoz (višji proizvodni stroški znižajo konkurenčnost gospodarstva), znižanje uvoza pa sledi dinamiki bruto domačega proizvoda. Učinek na sektor države je tudi negativen. Le DDV se za kratek čas poveča (višja cena se pomnoži s stopnjo DDV), kasneje, ko sledi prilagoditev zasebne potrošnje v negativno smer, pa prilivi iz naslova DDV padejo.[69] Vse ostale oblike davkov se znižajo. Končni rezultat je povišanje proračunskega deficita, ki svoj vrh v višini 0.02 o. t. BDP doseže po približno dveh letih in pol.

[69] V primeru, da bi do povišanja cene elektrike prišlo zaradi dviga prispevkov ali trošarin, ki jih lahko razumemo kot priliv v širši sektor države, bi to dodatno okrepilo prihodke proračuna na kratek rok.

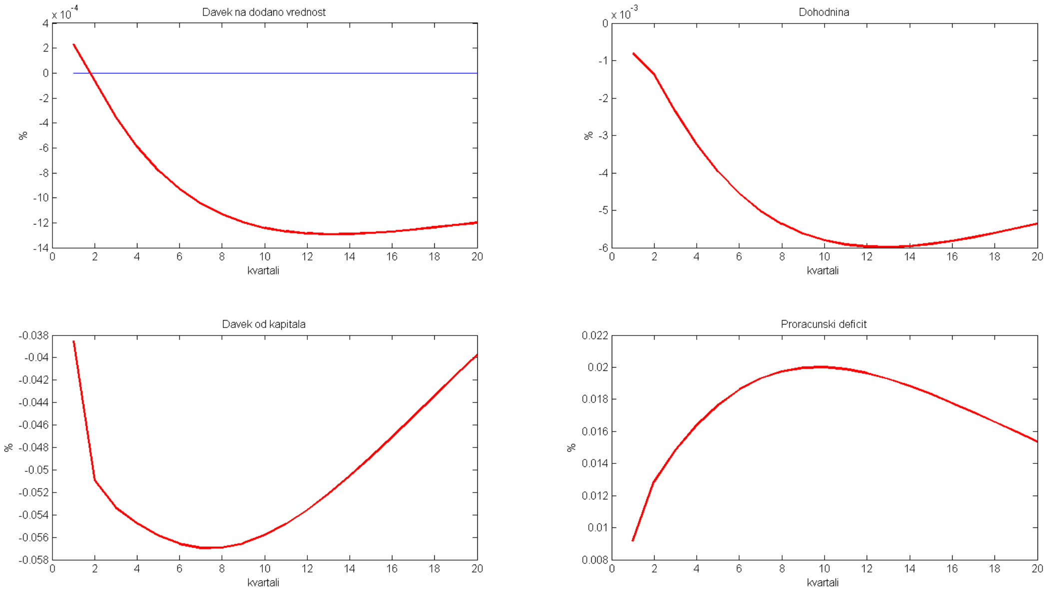
Figure R.6: *Simulacija vpliva persistentnega dviga grosističnih cen elektrike za 1 % - vpliv na ključne makroekonomske agregate*



Opombe: Odzivi spremenljivk so prikazani kot odstopanje od ustaljenega stanja. Časovni horizont od nastanka šoka je merjen v četrtletjih.

Vir: Lasten prikaz.

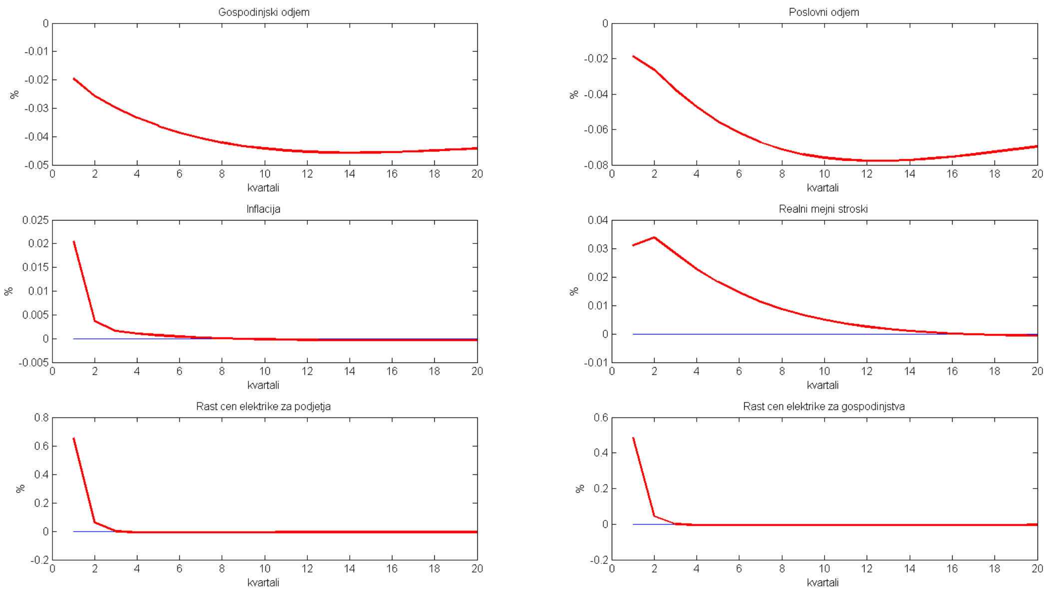
Figure R.7: *Simulacija vpliva persistentnega dviga grosističnih cen elektrike za 1 % - vpliv na državni proračun*



Opombe: Odzivi spremenljivk so prikazani kot odstopanje od ustaljenega stanja. Časovni horizont od nastanka šoka je merjen v četrtletjih.

Vir: Lasten prikaz.

Figure R.8: *Simulacija vpliva persistentnega dviga grosističnih cen elektrike za 1 % - vpliv na inflacijo in odjem elektrike*

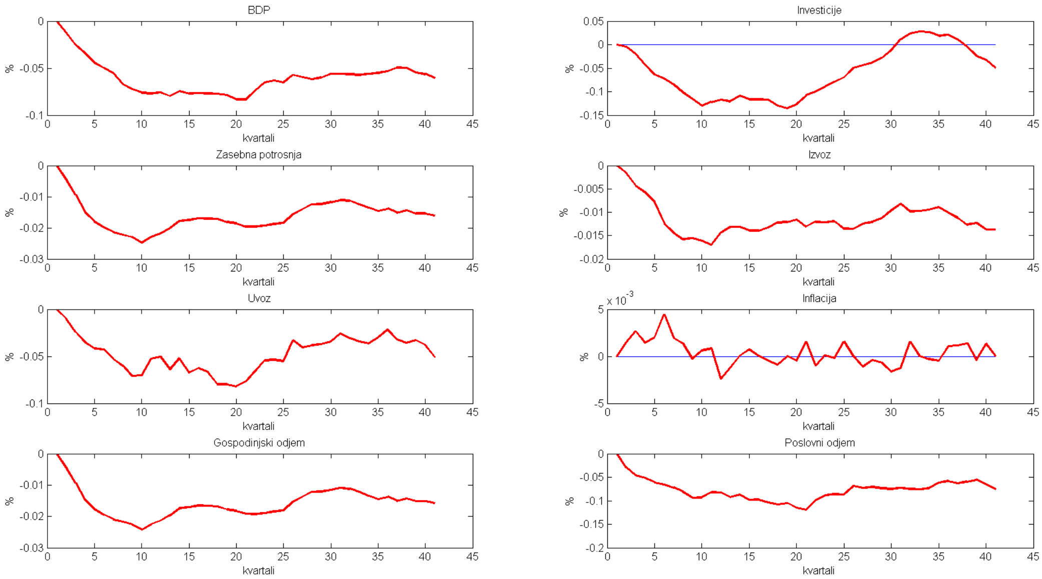


Opombe: Odzivi spremenljivk so prikazani kot odstopanje od ustaljenega stanja. Časovni horizont od nastanka šoka je merjen v četrtletjih.

Vir: Lasten prikaz.

Električna energija vstopa v model tako na strani potrošnje gospodinjstev kot tudi proizvodni dejavnik na strani proizvodnje dobrin. S tega vidika je možno z modelom primerjati, kakšne bi bile makroekonomske posledice parcialnih podražitev, tj. ločenih podražitev elektrike za gospodinjski in poslovni odjem. Zaradi preglednosti so prikazani le učinki na ključne makroekonomske agregate, torej komponente bruto domačega proizvoda in inflacijo. Vpliv dviga cene za poslovni odjem je prikazan na Sliki (R.9), za gospodinjski odjem pa na Sliki (R.10). V obeh primerih gre za 1-odstotno podražitev elektrike, ki se zgodi v enem četrtletju, kasneje pa podražitev ni več. Opaziti je možno, da ima podražitev elektrike za poslovni odjem večje negativne učinke na ekonomsko aktivnost. Povzroči enoznačne negativne učinke na bruto domači proizvod, ki je vztrajnejši in v absolutnem smislu v točki največjega negativnega vpliva praktično osemkrat večji. Podobno je moč opaziti pri vplivu na investicije, izvozu in uvozu. Le pri zasebni potrošnji po pričakovanjih ni tako, saj ima v tem primeru podražitev elektrike za gospodinjski odjem večji negativni vpliv. Ker ima podražitev elektrike za poslovni odjem vztrajen negativen učinek na stroške poslovanja podjetij, je močnejši in dolgotrajnejši tudi vpliv na inflacijo. Iz rezultatov izhaja, da imajo šoki v cene elektrike tipične stagflacijske učinke.

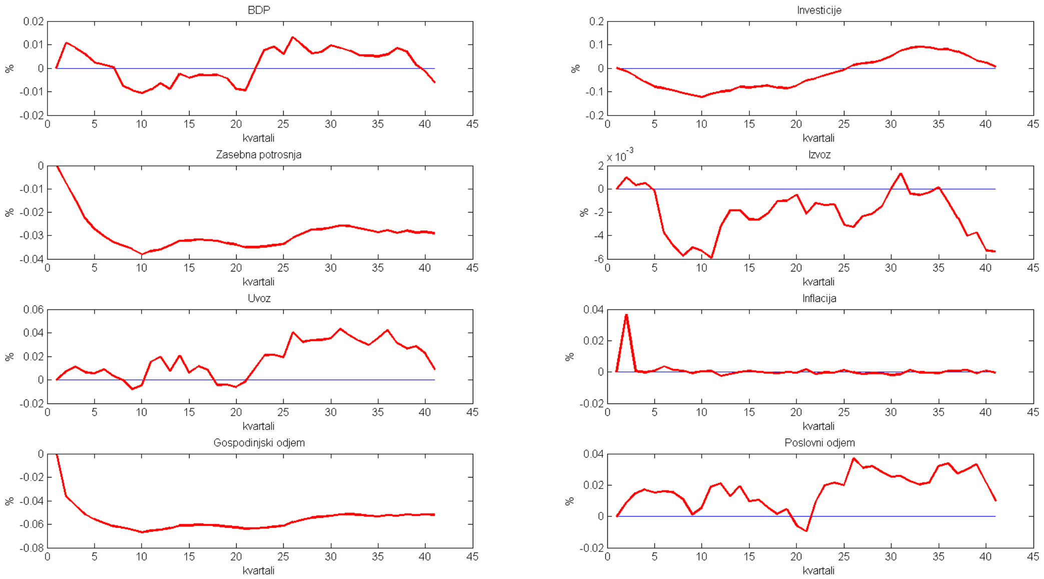
Figure R.9: *Simulacija vpliva trajnega dviga cen elektrike za poslovnih odjem za 1 % - vpliv na ključne makreokonomske agregate in odjem elektrike*



Opombe: Odzivi spremenljivk so prikazani kot odstopanje od ustaljenega stanja. Časovni horizont od nastanka šoka je merjen v četrtletjih.

Vir: Lasten prikaz.

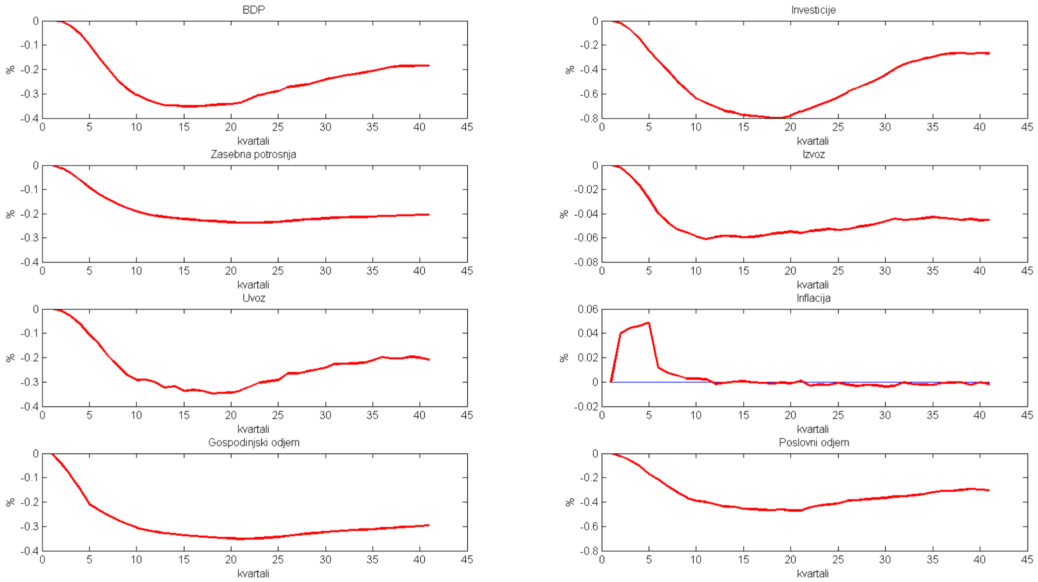
Figure R.10: *Simulacija vpliva trajnega dviga cen elektrike za gospodinjski odjem za 1 % - vpliv na ključne makreokonomske agregate in odjem elektrike*



Opombe: Odzivi spremenljivk so prikazani kot odstopanje od ustaljenega stanja. Časovni horizont od nastanka šoka je merjen v četrtletjih.
Vir: Lasten prikaz.

Nazadnje je prikazana simulacija nekoliko znatnejše spremembe cen električne energije, in sicer rast maloprodajnih cen po 1 % na četrtletje za obdobje enega leta, tj. 4 četrtletij. Kumulativno se cene dvignejo za dobre 4 %. Višje cene se, skladno z ocenjenim procesom gibanja cen elektrike, le postopno in v dolgem časovnem obdobju vrnejo nazaj v ravnovesje. Rezultati simulacije so predstavljeni na Sliki (R.11). Iz slike je razvidno, da ima sprememba občutne učinke na ekonomsko aktivnost. Bruto domači proizvod se na horizontu 3-4 let odkloni od svoje ravnovesne (trendne) ravni za približno 0.35 %. To pomeni za približno 140 mio EUR nižjo dodano vrednost na letni ravni. Le postopoma se BDP vrača k ravnovesju. Po 10 letih je še vedno za 0.2 % pod ravnjo siceršnje trendne rasti. Negativni so tudi učinki na ostale komponente bruto domačega proizvoda. Bruto investicije so po 4.5 letih nižje za 0.8 %. Podobno dinamiko kot bruto domači proizvod imata tudi zasebna potrošnja (padec je nekoliko nižji, vendar bolj vztrajen) in uvoz. Najmanjši učinek je na izvoz, ki se od trenda odkloni za manj kot desetino odstotka. Inflacija se zmerno poviša za obdobje 2 let. Povišanje inflacije je večje kot znaša delež elektrike v CPI, kar pomeni, da prihaja do pristiska na cene tudi zaradi upoštevanja višjih stroškov s strani podjetij. Odjem elektrike je nižji, dominantno pa ga žene nižja ekonomska aktivnost. Poslovni odjem se tako na horizontu 3-4 let zniža za dobre 0.4 %, znižanje gospodinjskega odjema pa je nekoliko nižje (0.35 %), vendar ima večjo vztrajnost.

Figure R.11: *Simulacija vpliva trajnega dviga cen elektrike za 4 % v obdobju enega leta - vpliv na ključne makreokonomske agregate in odjem elektrike*



Opombe: Odzivi spremenljivk so prikazani kot odstopanje od ustaljenega stanja. Časovni horizont od nastanka šoka je merjen v četrtletjih.

Vir: Lasten prikaz.

Znanstveni prispevek doktorske disertacije in možnosti za nadaljnje raziskave

V tem poglavju predstavljam znanstveni prispevek doktorske disertacije po posameznih poglavjih in predlagam nekaj možnosti za nadaljnje raziskave.

V prvem poglavju doktorske disertacije, ki nosi naslov *Dekompozicija slovenskega poslovnega cikla: rezultati ocenjenega DSGE modela*, so glavni prispevki naslednji: (i) z metodološkega vidika je doprinos tega poglavja ocena strukturnih parametrov in šokov modela na podlagi Bayesianske metode, kar po mojem najboljšem vedenju predstavlja prvi članek z ocenami DSGE modela srednjega za slovensko gospodarstvo; (ii) z empiričnega vidika je doprinos tega poglavja v identifikaciji strukturnih šokov, ki so bili v ozadju poslovnega cikla v Sloveniji, s poudarkom na nedavnih obdobjih recesije; (iii) poleg tega ima poglavje tudi praktični doprinos, saj je model možno uporabiti kot podporno orodje pri vodenju ekonomske politike. Rezultati tega poglavja odpirajo možnosti za nadaljnje raziskovanje, kar izhaja predvsem iz omejitev modela, ki jih predstavljam v nadaljevanju. Model, ki sem ga uporabil, ne vsebuje finančnih šokov, ki so bili v ospredju zadnje recesije. V prihodnosti bi lahko v model vključil vsaj tri finančne šoke. Prvi finančni šok bi bil lahko povezan z nenadno izgubo finančnih virov slovenskih bank na mednarodnih trgih. Znano je, da je Slovenija v letih pred krizo doživljala prekomerno kreditno rast, ki je temeljila predvsem na zadolževanju v tujini. Ob nastopu recesije se je dotok poceni kreditov iz tujine ustavil, kar je povečalo bančne obrestne mere in stroške financiranja. Drugi finančni šok bi bil lahko posledica neustreznih odločitev slovenskih bank glede dodeljevanja kreditov v preteklosti, kar je povzročilo kopičenje slabih kreditov v bilancah bank, kar je ponovno povečalo obrestne mere in znižalo kreditno aktivnost. Tretji finančni šok pa bi bil lahko povezan s krizo državnega dolga, ki je temu sledila. Zaradi nje se je poslabšala kreditna sposobnost Slovenije, kar je povečalo stroške zadolževanja v gospodarstvu.

Druga omejitev, ki jo lahko izpostavim, je, da pri ocenjevanju modela nisem upošteval spremembe monetarnega režima, do katerega je prišlo leta 2007, ko je Slovenija uvedla evro. Od osamosvojitve naprej je Banka Slovenije, kot osrednja institucija, pristojna za izvajanje denarne politike, vodila denarno politiko, ki je bila usmerjena v ciljanje denarnih agregatov (monetarno ciljanje). Do leta 1997 je uporabljala denarni agregat M1, od takrat naprej pa širši denarni agregat M3. Od leta 2001 naprej je postal glavni cilj Banke Slovenije postopno zniževanje inflacijskih stopenj pred vstopom Slovenije v ERM II mehanizem. S tem je Banka Slovenije prešla na nov okvir denarne politike, ki je bil bližje inflacijskemu ciljanju (Caprirolo & Lavrač, 2003). Ker bi bilo z modelskega vidika takšen preplet različnih režimov težko modelirati, še posebej v modelu takšnega obsega kot sem ga uporabil v doktorski disertaciji, sem v tem delu ohranil strukturo modela čim bolj preprosto. Izognil sem se tudi nepremišljenemu vključevanju različnih Taylorjevih pravil, kot svarijo Cúrdia et al. (2012). V modelu, ki sem ga ocenil za Slovenijo, sem ohranil samo modificiran UIP pogoj, ki je izpeljan iz pogojev prvega reda držanja domačih in tujih obveznic, in ki povezuje domačo obrestno mero s tujo obrestno mero ter premijo za tveganje. S tehničnega vidika je obstoj slednje potreben za zagotovitev stacionarnosti ustaljenega stanja v modelu majhnega odprtega gospodarstva (glej Schmitt-Grohe & Uribe, 2003). Natančneje, za začetna leta v vzorcu, ko Slovenija še ni bila del EMU, bi bilo potrebno v prej omenjeno relacijo dodati člen ΔS_{t+1}, ki bi predstavljal nominalni devizni tečaj. Poleg tega bi nominalni devizni tečaj vplival tudi na pogoje menjave. Vendar pa bi bil tak model nerešljiv, saj bi bilo potrebno za njegovo rešljivost vanj vključiti tudi monetarno pravilo. Vključitev nominalnega deviznega tečaja za začetna leta v vzorcu bi vplivala na pogoje menjave. Posledica pa bi lahko bil tudi manjši (večji) vpliv posameznih strukturnih šokov, odvisno od njihove narave. Na podlagi ugotovitev iz Cúrdia et al. (2012), lahko predvidevam, da bi bilo doseženo tudi boljše prileganje modela podatkom. V DSGE literaturi obstaja kar nekaj primerov modelov, v katerih so avtorji modelirali denarno politiko na poenostavljen način (glej npr. Adolfson et al., 2007; Almeida, 2009; Smets & Wouters, 2003; Marcellino & Rychalovska, 2014 in drugi). Problem teh modelov je v tem, da so ocenjeni na implicitni predpostavki obstoja skupne denarne politike, še preden se je le-ta dejansko začela izvajati. To pomeni, da je s tem kršena predpostavka o obstoju različnih denarnih politik in fleksibilnih deviznih tečajev pred letom 1999. Tak pristop pa tudi ne upošteva strukturnih posebnosti posameznih gospodarstev. Kljub poenostavljenemu pristopu k modeliranju denarne politike, model, ki sem ga ocenil za Slovenijo, relativno dobro pojasnjuje gibanje makroekonomskih spremenljivk skozi opazovano časovno obdobje. To kažajo enostranske napovedi Kalmanovega filtra, ki jih je možno interpretirati kot prileganje modela podatkom. Da bi preveril robustnost dobljenih rezultatov, sem model ocenil tudi za krajše časovno obdobje, ko je Slovenija vstopila v mehanizem deviznih tečajev ERM 2 (od leta 2004Q3 naprej). Rezultati kažejo, da se ocene parametrov bistveno ne spremenijo, čeprav je morda v tem primeru zaznati nekaj več težav z njihovo konvergenco. Poleg tega tudi ugotavljam, da ni bistvenih sprememb glede glavnih rezultatov, ki so predstavljeni v okviru poglavja (npr. pri rezultatih historične dekompozicije).

Drugo poglavje z naslovom *Ovrednotenje fiskalnih pravil v ocenjenem DSGE modelu*, v katerem sem analiziral delovanje različnih fiskalnih pravil, vsebuje naslednje prispevke k znanosti: (i) analizo impulznih odzivov izbranih makroekonomskih spremenljivk (rasti proizvoda, rasti državne potrošnje, proračunskega salda in javnega dolga) na negativni investicijski šok pod proučevanimi fiskalnimi pravili; (ii) vpliv proučevanih fiskalnih pravil na volatilnost izbranih makroekonomskih spremenljivk; (iii) protidejstveni eksperiment, s katerim sem simuliral, kakšno bi bilo gibanje izbranih makroekonomskih spremenljivk za Slovenijo med letoma 1995 in 2014, če bi bila v veljavi proučevana fiskalna pravila. Kljub temu da poglavje nudi pomembne zaključke glede vodenja fiskalne politike v prihodnje, je potrebno nanj gledati kot na začetek bolj poglobljene analize fiskalnih pravil, saj bi ga bilo možno nadgraditi na številnih področjih. Nadaljnje raziskovanje bi se lahko osredotočilo na analizo različnih fiskalnih instrumentov (kot so npr. različne davčne stopnje), ki bi se prilagajali na način, da bi bilo zadoščeno obravnavanim fiskalnim pravilom. Poleg tega bi bilo možno oblikovati enostavna fiskalna pravila za različne instrumente fiskalne politike, namesto trenutno uporabljene državne potrošnje. Naslednja možna razširitev poglavja bi bila analiza medsebojnega vpliva denarne in fiskalne politike ter njun vpliv na obstoječe rezultate. V tem smislu bi lahko poiskali najboljše možne kombinacije ukrepov denarne in fiskalne politike ob različnih šokih, ki vplivajo na gospodarstvo. Prav tako bi bilo smiselno obstoječi model razširiti v smislu vpeljave koristne javne porabe, bodisi tako, da bi poraba javnih dobrin vstopala neposredo v funkcijo koristnosti gospodinjstev, kot tudi tako, da bi državna potrošnja vplivala na povečanje produktivnosti. V prihodnosti bi lahko pri ocenjevanju modela uporabil tudi fiskalne spremenljivke. In nazadnje, model bi lahko prilagodil tudi tako, da bi omogočal uporabo drugih simulacijskih metod, na primer takšnih, ki bi dopuščale izvedbo pogojnih simulacij (kot npr. v IMF, 2009). Na ta način bi bilo možno simularati delovanje fiskalnih pravil ob različnih predpostavkah gibanja prihodnje gospodarske rasti in proizvodne vrzeli ter drugih simulacijskih scenarijih.

Prispevek tretjega poglavja, ki nosi naslov *Elektrika v DSGE modelu*, je naslednji: prvič, z metodološkega vidika to poglavje razvija analitični okvir, ki temelji na DSGE modelu, ki je primeren za izvajanje analiz, povezanih s cenami električne enrgije. Po najboljšem vedenju gre za prvi poskus vključitve električne energije v DSGE model, ki upošteva specifične značilnosti slovenskega trga električne energije. Empirični prispevek tega poglavja izhaja iz ocen učinkov sprememb cen električne energije na slovensko gospodarstvo. In nazadnje, praktični prispevek tega poglavja je, da je v njem predstavljen model, ki ga je možno uporabiti za praktične namene znotraj elektroenergetskega podjetja. Pričujoče poglavje je nastalo kot odziv na prošnjo enega od teh podjetij po razvoju in kalibraciji modela za Slovenijo, ki bi zaposlenim omogočal samostojno izvajanje simulacij. Kot pomanjkljivost modela je možno izpostaviti dejstvo, da elektrika v njem nastopa kot edini energetski vir, kar pomeni, da so lahko zaradi neobstoja možnosti substitucije elektrike z drugimi viri energije učinki sprememb cen elektrike na ekonomske kategorije nekoliko pristranski. Poleg vključitve drugih virov energije (npr. nafte) bi bilo možno model dopolniti tudi s specifikacijo elektroenergetskega sektorja, kar pa je prepuščeno nadaljnjemu razvoju in vzdrževanju modela.