Monetary and Fiscal Policy Analyses in Estimated DSGE Models

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Chapter 1

Overview

Given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models.

Lucas (1976)

Literature review

Over the past decades, dynamic stochastic general equilibrium (DSGE) models have become standard tools in macroeconomics. Their inherent microfoundations, the explicit specification of intratemporal as well as intertemporal objectives and constraints of economic agents, render them immune to the above-quoted Lucas critique. Econometric models in the Keynesian tradition, on the other hand, that rely on correlations of economic variables based on historical data inevitably lead to inaccurate conclusions on the consequences of policy measures, as their parameters are subject to time-variance. Indeed, it were the traditional Keynesian prescriptions to stimulate demand that did not work in the wake of the two oil-price shocks of the 1970s and caused a period of high and persistent inflation in the United States.

Largely owing to the latter, macroeconomic theories of rational expectations postulated in the preceding years (Muth, 1961; Lucas, 1972) gained momentum and finally resulted in the seminal work on the theory of real business cycles (RBCs) of the future Nobel laureates Kydland and Prescott (1982), with their general equilibrium model being considered the first example of a DSGE model. The main innovation of their approach to the analysis of business cycles is the assumption of the stochastic nature of cycles at the equilibrium trajectories of changes in the main macroeconomic indicators. This assumption in RBC theory is fundamentally different from all other concepts. In contrast to the earlier Keynesian view of the additive effect of uncertain shocks on the deterministic equilibrium, Kydland and Prescott (1982) argue that shocks have a certain nature and should be directly implemented into an economic system. Prescott (1986) found his model built on these thoughts being capable to generate data that by and large corresponded to the historical time series. According to this, fluctuations of real macroeconomic variables around their equilibria were caused by shocks to total factor productivity. Despite these promising characteristics, early RBC models had serious shortcomings. In particular, they did not feature money as well as any market frictions or imperfections. Instead, they were assuming perfect competition on all markets, absolute rationality and fully flexible prices and wages. Consequently, neither monetary nor fiscal policy had any effects on real variables.

New Keynesian economics emerged to address these fundamental shortcomings. Its achievements included the explicit modeling of monopolistically competitive firms to rationalize the price setting with a markup over marginal costs (Blanchard and Kiyotaki, 1987), and microfoundations of sticky wages and prices that are addressed by the introduction of quadratic adjustment costs (Rotemberg, 1982) or random price adjustment signals (Calvo, 1983), among others. The combination of elements from both schools of thought, in particular the neoclassical idea of a general equilibrium on a balanced growth path and new Keynesian market imperfections, resulted in the framework that is commonly referred to as the new neoclassical synthesis (NNS) and which is the foundation for practically all modern DSGE models. In these, the economy is populated by a representative household who maximizes its lifetime utility subject to an intertemporal budget constraint and a continuum of monopolistically competitive firms. Market power of the latter leads them to set prices higher than their marginal costs, making it profitable to meet all demand in the short-term at prevailing rigid prices. Price rigidity results in the non-neutrality of money in the short-term and, thus, in the capacity of the monetary policy to influence the real economy.

The most simple NNS model (e.g. Clarida et al., 1999) is composed of three equations: an expectation-augmented IS curve, a new Keynesian Phillips curve and a monetary policy rule in the spirit of Taylor (1993). Adding demand shocks to the IS equation (e.g. preference shocks, government spending shocks), supply shocks to the Phillips curve (e.g. technology shocks, cost-push shocks) and a shock to the monetary policy rule, enables the analysis of the dynamics of model variables following these kinds of disturbances as well as optimal monetary policy reactions in response to them.

Depending on the focus of interest, the basic framework has been expanded in many different ways.[1] This is in particular true for models that were built to be estimated using actual data, as specific dynamics observed in the latter needed to be captured by the structure of the model. The most commonly used modifications comprise the inclusion of external habit formation, smoothing the dynamics of private consumption. Christiano et al. (2005) and Smets and Wouters (2003) augment the simple framework by introducing investment into productive capital that is rented out to producers, with investment itself and also the utilization rate of installed capital being subject to specific adjustment costs that facilitate the model's ability to capture observed delays in the dynamics of the respective variables to changes in variables explaining their behavior. Monacelli (2005) and Galí and Monacelli (2005) extend the simple NNS model to a small open economy (SOE) framework, in which households not only decide on the optimal level of consumption but also on the optimal composition of home and foreign goods in the consumption basket. Furthermore, savings can be allocated to domestic and international bonds, resulting in an endogenous uncovered interest parity condition, augmented by a risk premium to prevent indefinite foreign borrowing (Schmitt-Grohe and Uribe, 2003), and respective exchange rate dynamics. Even in its simplistic form, the SOE model provides insight on how foreign shocks affect the domestic economy, through which channels and how monetary policy can mitigate or amplify them. In particular, the set of possible policy targets can be extended to various types of nominal and real exchange targeting.

As concerns the analysis of direct effects of fiscal policy measures, basic DSGE models fail for reasons of their inherent assumption of Ricardian equivalence. Given a balanced public budget over time and the assumption of households directing their savings to government bonds, changes in government spending and taxes do not alter the present value of lifetime income of households and consequently their spending plans. To match the model structure to observed crowding-in effects, Galí et al. (2007) build on previous work on non-Ricardian, i.e. non-optimizing, agents by Mankiw (2000). These kinds of consumers are supposed to have no access to financial markets so that they cannot smooth consumption intertemporally

[1] A detailed survey on various extensions of the basic model framework is presented e.g. in Tovar (2008).

and thus consume their entire disposable income in every period. Under this assumption, fiscal policy has direct real effects on the economy through the increased (decreased) spending of non-Ricardian households following tax reductions (increases) as well as changes in the amount of labor supplied following lump-sum payments received. The impact of fiscal policy on the economy in a DSGE model framework can further be influenced by the assumption of productive public capital, in particular as a substitute for private capital, following the seminal work by Barro (1990), as well as assumptions about the representative household's non-separable utility being a function of public spending (e.g. Linnemann and Schabert, 2003).

For many years, the calibration of DSGE models constituted their most prominent use. Thereby, numerical values for model parameters are assigned grounded on microeconomic studies or based on long-term averages. This approach enables the analysis of the impacts of shocks and the identification of the respective channels through which they affect the economy as well as how policy can mitigate or amplify the effects. However, fully calibrated models also have their shortcomings, primarily due to the fact that some parameters might be difficult to quantify accordingly with the help of micro studies and that parameter uncertainty cannot be incorporated into the system of equations. Taking the model to actual data, on the other hand, addresses both drawbacks and enables analyses not only on the basis of theoretical moments but also observed historical ones.

Various methods for the estimation of DSGE models have emerged over time, with Maximum Likelihood (ML), Generalized Methods of Moments (GMM), Simulated Methods of Moments (SMM) being the most often used procedures. Ruge-Murcia (2007) examines the small-sample properties of the approaches mentioned to conclude that all of them are affected in their own specific way by the stochastic singularity of linearized DSGE models. Whereas ML estimation is limited by the number of linearly independent variables, the other two are constrained by the number of linearly independent moments. However, he argues that ML estimates can be substantially improved in terms of more economically reasonable values and in a lower bias of the estimates and the variance of their small-sample distributions when incorporating Bayesian priors. As argued by An and Schorfheide (2007), the advantage using Bayesian methods compared to GMM is the simultaneous estimation of all model equations that allows for a more profound interpretation of structural shocks and their transmission, facilitating the model-based assessment of policy measures. In addition, prior knowledge and thus additional information can be directly incorporated into the parameter estimation. Regarding the latter characteristic, a DSGE model estimated with Bayesian techniques thus combines the advantages of a calibrated model and a complete estimation, while also constituting a compromise with respect to the disadvantages of both approaches.

Indeed, Bayesian methods gained increased popularity in the estimation of DSGE models during the last decade, partly also due to advances in the processing power of computers and specific applications. In particular, the development of the MATLAB pre-processor Dynare (see Adjemian et al., 2011), offering a user-friendly and intuitive platform to specify model equations, parameter values and to solve, estimate and simulate the model, substantially facilitated the work with DSGE models and consequently widened its utilization in academia and institutions. Nowadays, central banks around the world rely on DSGE models to analyze policy implications and conduct forecasts (e.g. Brubakk et al., 2006; Erceg et al., 2006; Adolfson et al., 2007b; Murchison and Rennison, 2006).

Christiano et al. (2005), Smets and Wouters (2003) and Smets and Wouters (2007) were the first to estimate fully specified DSGE models and to provide evidence about their ability to fit and forecast time series compared to different approaches, in particular vector autoregressive models. Their standard model framework has been extended in various ways to be estimated in the context of specific research questions. Examples include Adolfson et al. (2007a) who include open economy aspects to analyze monetary policy and its effects on the economy, Gertler et al. (2008) who introduce unemployment in line with staggered nominal wage contracting, as well as a large number of studies incorporating specific features to assess the effectiveness of fiscal policy measures (e.g. Ratto et al., 2009; Iwata, 2009; Cogan et al., 2010; Coenen et al., 2012).

The baseline SOE model by Galí and Monacelli (2005) has been estimated in its simple form by Lubik and Schorfheide (2007), analyzing monetary policy of Australia, Canada, New Zealand and the UK. Justiniano and Preston (2010) extend the original model framework by additional market imperfections to also estimate it for the first three economies mentioned. Other early contributions to the Bayesian estimation of SOE models include Ambler et al. (2004), Bergin (2003) and Dib (2011). DSGE models have further been specified to be explicitly used for macroeconomic forecasting purposes (e.g. Carabenciov et al., 2008; Giesen et al., 2012).

Although, due to their microfoundations, parameters of DSGE models have long been regarded as time-invariant, a branch of the economic literature emerged in the past decade arguing for the opposite. Research in this field has been empirically motivated by the work of Fernández-Villaverde and Rubio-Ramírez (2007). The authors estimated that parameters in structural models, in particular those affecting the price setting behavior of firms, are subject to drifts, since they are affected by fundamental changes in monetary policy. One possible way to account for this time-invariance is the specification of Markov-switching

DSGE (MS-DSGE) models that assume the existence of distinct regimes with respectively different parameter values assigned to them. In these kinds of models, agents do not only form expectations about future realizations of model variables in one regime, but also about the probability of regime switches in the upcoming periods since that would consequently also affect the former via different expected parameter values. Davig and Leeper (2007), Davig and Leeper (2006) and Farmer et al. (2006), among others, addressed the technical aspects of modeling different policy regimes in a MS-DSGE framework. Early contributions to the estimation of MS-DSGE models focused on regime switches in monetary policy rules (e.g. Davig and Doh, 2008; Bianchi, 2010). More recently, models have also been estimated allowing for regime switches in all of their parameters and standard deviations of shocks (e.g. Liu and Mumtaz, 2010).

Chapter overview

This thesis consists of three individual chapters on the analysis of particular policy strategies and measures in estimated DSGE models. In Chapter 2, we estimate a Markov-switching DSGE model for the Czech Republic, Hungary and Poland to quantify changes in the implementation of monetary policy with the introduction of inflation targeting. In Chapter 3, a DSGE model is set up to account for specific features of the Russian economy to subsequently evaluate the estimated monetary policy in place in the presence of external shocks. Chapter 4 analyzes the effects of German fiscal stimulus measures during the Great Recession.

Chapter 2, *Switching to Exchange Rate Flexibility? – The Case of Central and Eastern European Inflation Targeters* (Drygalla, 2015), addresses the possible time-invariance of model parameters and shocks in the context of the switch of monetary policy from exchange rate to inflation targeting in the Czech Republic, Hungary and Poland around the turn of the millennium. The analysis focuses on three main aspects. First, an estimation is carried out to quantify the changes in the conduct of monetary policy following the implementation of the new strategy. In particular, whether or not the dynamics of the exchange rate and the rate of consumer price inflation gained a decreased or increased attention of the central banks, respectively. Second, it is assessed to which extent the timing of the official introduction of the new policy and its actual implementation have coincided. Finally, we address the question to which extent the new strategy can be considered as effective in the sense of having reduced the volatilities of possible target variables. Therefore, simulations are conducted in which estimated distinct regimes of monetary policy as well as high and low volatilities of disturbances are combined to fictional scenarios. The performance of different policy strategies is subsequently assessed on the basis of how effective they prove in the mitigation of equal-size shocks on domestic variables. Whereas the first two question have been addressed in comparable studies for other economies (e.g. Liu and Mumtaz, 2010; Alstadheim et al., 2013), the analysis of the third aspect is, to the best of my knowledge, the first of its kind in the economic literature so far.

Against the background of large and continuous capital outflows and a sharp drop in oil prices in the year 2014, putting depreciation pressure on the Russian ruble and leading to an intense reaction of the monetary policy, Chapter 3 of this thesis, *Monetary Policy in an Oil-Dependent Economy in the Presence of Multiple Shocks*, analyzes the latter in the framework of an estimated DSGE model designed to feature important characteristics of the Russian economy. In particular, a standard SOE model is extended by the inclusion of productive capital, an oil exporting sector and a microfounded foreign exchange market on which the central bank intervenes via sales and purchases of foreign securities to influence the behavior of the nominal exchange rate. Following the estimation of the model parameters and intensities of disturbances, the impacts of shocks on domestic variables are quantified, both, historically and based on the properties of the model and the economy. Subsequently, the actual monetary policy is compared to reasonable alternatives on the basis of the implications that is has to shield domestic variables from external disturbances. A particular focus is put on shocks to the oil price, capital flows as well as both shocks occurring simultaneously. The study differs from comparable analyses in the sense that it explicitly considers the foreign exchange market, interventions carried out by central bank and their respective implications for the dynamics of the exchange rate and the associated effects on the economy as a whole.

Chapter 4, *The Effects of Fiscal Policy in an Estimated DSGE Model – The Case of the German Stimulus Packages during the Great Recession*, written jointly with Oliver Holtemöller and Konstantin Kiesel, analyzes the effects that fiscal policy measures adopted to counter the Great Recession actually had in the case of Germany. Therefore, an otherwise standard medium-scale DSGE model is extended by non-optimizing households and to feature the fiscal sector in a rich way. In particular, the dynamic behavior of spending and revenue variables is specified in feedback rules according to which they are explained by the cyclical output component. In doing so, we explicitly account for automatic stabilizer characteristics of fiscal policy so that non-systematic deviations from the rules can be regarded as discretionary policy and thus as true and unexpected impulses. The impact that policy measures have had on the output is subsequently assessed on the basis of a historical shock decomposition of the latter. In contrast to a large number of studies on fiscal multipliers, our work is one of the first to quantify the effects of fiscal policy measures in Germany in an estimated DSGE model framework.

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Chapter 2

Switching to Exchange Rate Flexibility? The Case of Central and Eastern European Inflation Targeters

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Abstract

This chapter analyzes changes in the monetary policy in the Czech Republic, Hungary, and Poland following the policy shift from exchange rate targeting to inflation targeting around the turn of the millennium. Applying a Markov-switching dynamic stochastic general equilibrium model, switches in the policy parameters and the volatilities of shocks hitting the economies are estimated and quantified. Results indicate the presence of regimes of weak and strong responses of the central banks to exchange rate movements as well as periods of high and low volatility. Whereas all three economies switched to a less volatile regime over time, findings on changes in the policy parameters reveal a lower reaction to exchange rate movements in the Czech Republic and Poland, but an increased attention to it in Hungary. Simulations for the Czech Republic and Poland also suggest their respective central banks, rather than a sound macroeconomic environment, being accountable for reducing volatility in variables like inflation and output. In Hungary, their favorable developments can be attributed to a larger extent to the reduction in the size of external disturbances.

2.1 Introduction

Among other countries, the Central and Eastern European (CEE) transition economies of the Czech Republic, Poland, and Hungary adopted the monetary strategy of inflation targeting around the turn of the millennium. Officially announced inflation targets started to act as nominal anchors for monetary policy. Prior to that, the exchange rates of their respective currencies have explicitly been targeted by their central banks.

The Czech National Bank (CNB) that has been committing to an exchange rate target against a currency basket composed of the German mark and the US dollar let the koruna float after not having being able to sustain devaluation pressures during May 1997. Consequently, inflation targeting was introduced as a new nominal anchor for monetary policy in the beginning of 1998. For most of the time since then the exchange rate has been given minor attention. However, at the end of 2013 the CNB announced to prevent an appreciation of its currency below 27 koruna per euro to tackle an ongoing undershooting of its inflation target while being confronted with the zero lower bound for policy rates.

Somewhat different reads the story of the Hungarian forint. Prior to the introduction of inflation targeting, the national bank (MNB) has been operating a narrow +/- 2.25 percent crawling band regime for its currency. In the presence of large capital inflows, the MNB was not capable of preventing an excessive appreciation and to sufficiently sterilize the interventions at the same time to limit inflation pressures. Therefore, the exchange rate band was widened to 15 percent around the target rate against the euro in May 2001. An explicit inflation target to replace the exchange rate as a nominal anchor for monetary policy was introduced shortly thereafter. Hence, in contrast to the Czech Republic, the introduction of the inflation targeting framework did not come as a consequence of the central bank not being able to meet its exchange rate target due to capital outflows and resulting devaluation pressures. In Hungary, the switch from exchange rate to inflation targeting can rather be seen as an intentional policy change for a better fulfillment of the major objective of price stability.

Nearly the same applies to Poland, where the national bank (NBP) gradually widened the band around a preannounced depreciation rate of its currency during the 1990s. The crawling band was finally abolished turning the zloty into a free floating currency in April 2000. Inflation targeting as a new framework for monetary policy was already introduced at the beginning of 1999.

According to the International Monetary Fund (IMF) classification, the Polish and Czech currencies have become more flexible with the introduction of inflation targeting by moving from a managed floating to a free floating (Poland) and from a fixed to a managed floating regime (Czech Republic) respectively, whereas the forint remained being classified as a managed float. Following this, the move away from the exchange rate as a policy target did not lead to more flexibility of the Hungarian currency, neither had its rate been kept fixed before. Nonetheless, the scope of its allowed movements has been substantially widened ahead of the introduction of the new monetary policy framework. Following the *de facto* classifications of Ilzetzki et al. (2010), none of the currencies has become more flexible. The actually realized strategy in terms of monetary policy responses to exchange rate movements before and after the target shift remains vague for all three central banks. Neither obvious is the actual timing of the switch as well as the persistence of the new strategy and especially the adherence to it in periods of crises.

Following the seminal work of Taylor (1993), a broad field of literature on the estimation of monetary policy rules has emerged. The initial study that aimed at an explanation of policy rates through deviations of the inflation rate and output from their respective target values has been enhanced in many different ways. Examples include the introduction of an interest rate smoothing parameter (Clarida et al., 1998), specifications that feature other target variables, such as nominal GDP (McCallum, 2000), and the consideration of forward-looking variables (e.g. Batini and Haldane, 1999). Whereas monetary policy rules can be specified in a detailed manner to best fit historical data, they are most commonly estimated in a standalone way, not accounting for interactions between the monetary authority and the behavior of other agents in the economy. In particular, the extent to which policy measures can have an impact on the private sector's actions and expectations is not taken into account. In this context, dynamic stochastic general equilibrium (DSGE) models have gained importance. In contrast to univariate analyses, they provide a consistent framework for and thereby also a clearer interpretation of domestic and foreign economic shocks and the channels through which they affect particular variables.

However, as outlined before, the economies under consideration in this study have experienced structural and economic changes over the past decades. Whereas, due to their microfoundation, parameters of estimated DSGE models have initially been regarded as invariant to policy changes, a large literature emerged arguing for the opposite. As one of the first, Fernández-Villaverde and Rubio-Ramírez (2007) have found that standard DSGE model parameters are subject to drifts. In a recent study Hurtado (2014) built on their analysis and showed that estimated values of model parameters strongly depend on the underlying sample. Besides drifts in the values of structural parameters, there also seems to be a time-variance in the volatility of variables and disturbances hitting the economy, as the episode of the Great Moderation and the more turbulent periods before and thereafter suggest.

To adequately account for changes as well as to quantify them, this work estimates a simple small open economy model that allows for Markov-switches in its parameters and the volatilities of shocks and by that adds to the emerging literature on estimated Markov-switching dynamic stochastic general equilibrium (MS-DSGE) models. As one of the first, Davig and Doh (2008) as well as Bianchi (2010) estimated simple models for the United States, putting a focus on switches in the interest rate rule. A more complex model based on the work of Justiniano and Preston (2010) has been estimated for the United Kingdom by Liu and Mumtaz (2010). A more simple model of the UK economy based on Lubik and Schorfheide (2007) by Chen and MacDonald (2012) analyzes optimal and realized policy rules in a regime switching context. The same model setup is used by Alstadheim et al. (2013) to estimate the central banks' responses to exchange rate movements in Canada, Norway, Sweden, and the UK.

By applying the same framework to the Czech Republic, Hungary, and Poland, this study is the first, to the best of my knowledge, that analyzes monetary policy in CEE countries in a MS-DSGE model framework. By that, the timing and persistence of actual policy regime switches can be revealed. In addition, shifts in the central banks' strategies as well as in the volatility of shocks can be quantified. A revealed existence of different policy as well as volatility regimes further enables an assessment of the monetary policy compared to fictional scenarios in which different policy and volatility regimes are mixed. The achievement of objectives can thereby be classified as either a result of good policy or rather the presence of a favorable environment ('good luck'). Finally, the performance of the inflation targeting strategy can be evaluated in crises times.

The chapter is organized as follows: Section 2.2 outlines the model framework, the estimation process is described in Section 2.3, estimation results and an assessment of the monetary policies is presented in Section 2.4, Section 2.5 concludes.

2.2 Model

The model follows the simplified version of Galí and Monacelli (2005) outlined in Lubik and Schorfheide (2007). It consists of a forward-looking IS curve, a Phillips curve, a monetary policy rule and an equation linking CPI inflation, the nominal exchange rate, and the terms of trade. In more detail, by assuming a perfect substitutability between a variety of goods produced in one country as well as between home and foreign goods, a unit elastic labor supply, and by abstracting from investment and government spending, the standard Euler equation of utility maximizing households results in the following log-linearized IS curve:

$$y_t = E_t y_{t+1} - (\tau + \mu)(R_t - E_t \pi_{t+1} - \rho_z z_t) - \alpha(\tau + \mu) E_t \Delta q_{t+1} + \alpha(2 - \alpha)\frac{1-\tau}{\tau} E_t \Delta y^*_{t+1}, \quad (2.1)$$

with α being the share of imported goods in consumption, τ the intertemporal elasticity of substitution, and $\mu = \alpha(2 - \alpha)(1 - \tau)$. Intertemporal optimization of households results in consumption smoothing. Current values for consumption and thus output depend on their expected future realizations as well as the opportunity cost of current consumption in terms of foregone savings, the expected real interest rate $R_t - E_t \pi_{t+1}$. Furthermore, the rate of change in the terms of trade Δq_t, the relative price of imports in terms of exports, affects domestic output via the substitution of domestic for foreign goods. z_t is the growth rate of the global technology process, reflecting the non-stationary part of domestic as well as foreign output y^*_t.

Firms set their prices in a Calvo (1983)-manner. Each period only a random fraction of $(1-\theta)$ firms is able to set their prices to their optimal values in terms of profit maximization. This results in the consideration of expected future price levels in the current price setting. For the aggregate economy's price level it follows that:

$$\pi_t = \beta E_t \pi_{t+1} + \alpha\beta E_t \Delta q_{t+1} + \alpha \Delta q_t + \frac{\kappa}{\tau + \mu} y_t + \frac{\kappa + \mu}{\tau(\tau + \mu)} y^*_t, \quad (2.2)$$

where $\kappa = (1 - \theta)(1 - \theta\beta)/\theta$ is a measure of the degree of price rigidity dependent on the Calvo parameter θ. The impact of import prices on consumer price inflation is captured by the inclusion of the terms of trade. The last two factors reflect reactions of the price level to the degree of capacity utilization.

Domestic and foreign inflation, the terms of trade and the depreciation of the nominal exchange rate are linked under the assumption of purchasing power parity:

$$\Delta e_t = \pi_t - (1 - \alpha)\Delta q_t - \pi^*_t. \quad (2.3)$$

Monetary policy is characterized by a Taylor (1993)-type rule. The central bank sets the nominal interest rate R_t in reaction to movements in the inflation rate, the output gap, and the nominal exchange rate depreciation:

$$R_t = \rho_R R_{t-1} + (1 - \rho_R)(\psi_1 \pi_t + \psi_2 y_t + \psi_3 \Delta e_t) + \epsilon^R_t. \quad (2.4)$$

The remaining model variables, the terms of trade, technology as well as foreign output and inflation, are assumed to follow AR(1) processes in logs:

$$\Delta q_t = \rho_q \Delta q_{t-1} + \epsilon_t^q, \tag{2.5}$$

$$z_t = \rho_z z_{t-1} + \epsilon_t^z, \tag{2.6}$$

$$y_t^* = \rho_{y^*} y_{t-1}^* + \epsilon_t^{y^*}, \tag{2.7}$$

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \epsilon_t^{\pi^*}, \tag{2.8}$$

with $\epsilon_t^x \sim NID(0, \sigma_x^2)$ for $x \in \{q, z, y^*, \pi^*\}$.

2.3 Estimation

2.3.1 Regime switching

The model presented above can be put into state space representation of the general form:

$$\Gamma_0(\theta) X_t = \Gamma_1(\theta) X_{t-1} + \Psi(\theta)\epsilon_t + \Pi(\theta)\eta_t, \tag{2.9}$$

where X_t is a vector of endogenous variables, ϵ_t contains exogenous shocks, and η_t expectation errors. Γ_0, Γ_1, Ψ, and Π, are matrices, whereas θ contains the model parameters. The standard, time-invariant model can then be transformed into a regime switching version by letting the parameter vector θ being dependent on the exogenous stochastic process $S_t \in \{1, \ldots, M\}$ with M being the number of regimes that a Markov chain is allowed to follow. The transition probabilities with which the parameter vector is allowed to switch between different states takes the form:

$$\Pr[S_t = 1 \mid S_{t-1} = 1] = p_{11}, \tag{2.10}$$

$$\Pr[S_t = 2 \mid S_{t-1} = 1] = p_{12}, \tag{2.11}$$

$$\Pr[S_t = 1 \mid S_{t-1} = 2] = p_{21}, \tag{2.12}$$

$$\Pr[S_t = 2 \mid S_{t-1} = 2] = p_{22}. \tag{2.13}$$

The matrix of transition probabilities for one two-states Markov chain that is combined with the model equation can then be written as:

$$P = \begin{bmatrix} p_{11} & p_{11} \\ p_{21} & p_{22} \end{bmatrix}, \tag{2.14}$$

leading to a representation of the above outlined model following Farmer et al. (2011):

$$\bar{\Gamma_0} X_t = \bar{\Gamma_1} X_{t-1} + \bar{\Psi}\epsilon_t + \bar{\Pi}\eta_t, \tag{2.15}$$

with $\bar{\Gamma_0}$, $\bar{\Gamma_1}$, $\bar{\Psi}$, and $\bar{\Pi}$ combining the structural parameters and the transition probabilities. When forming expectations, agents thus explicitly take into account the transition probabilities, since a switch to another regime in the following period would result in different parameter values and by that alter the dynamics of the model variables.

The system is solved according to the Newton method outlined in Maih (2015), an extension of the minimum state variables solution proposed by Farmer et al. (2011), and estimated by means of Bayesian techniques using the RISE toolbox for MATLAB. However, due to the introduction of Markov-switching parameters and their unobserved states, the standard Kalman filter cannot be applied to compute the value of the likelihood, since it would take into account all possible combinations of Markov states in the past. Instead, an algorithm proposed by Kim and Nelson (1999) is adopted that approximates the Kalman filter by limiting the number of states that is carried forward at each period, so that the Kalman filter becomes workable.

Along with the benchmark model M_0 with time-invariant parameters and shocks, seven alternative specifications are estimated. In contrast to M_0, model M_1 allows for switches in the parameters of the interest rate rule, while M_2 is characterized by two regimes for the exogenous shocks. M_3 and M_4 combine the latter two specifications by allowing the policy parameters and the shocks to switch simultaneously. Whereas M_3 is characterized by one common Markov chain, M_4 sets up two independent chains for policy parameters and volatility respectively. Finally, M_5, M_6, and M_7 allow all coefficients and shocks to switch over the sample. In the first specification, all of them follow the same Markov chain. M_6 and M_7 again introduce two independent chains for policy parameters and shocks. The remaining coefficients then follow the same chain as the policy parameters (shocks) in the former (latter) specification.

2.3.2 Data

For the estimation the following five quarterly time series are used: log difference of real gross domestic product multiplied by 100 (ΔGDP_t), log difference of the consumer price index multiplied by 400 (ΔCPI_t), log difference of the terms of trade and the nominal exchange rate (NEER) index multiplied by 100 (ΔTOT_t and $\Delta NEER_t$), and the three-month interbank rate (INT_t).

All of the observable variables follow specific trends. These are the trends for the domestic output growth rates, for the inflation rate, as well as the domestic nominal interest rate. All of them, except for the latter, cannot been regarded as time-invariant. Taking the annual Polish inflation rate as an example, one obtains a sample average of more than 22 percent from 1994 to 1996 but only a value of less than 3 percent from 2000 to the present. Disregarding shifts in the average values of these parameters would result in imprecise assessments of the corresponding model variables, i.e. the deviations from the 'correct' trend, and thus in inaccurate estimations of the whole model. In the presence of a strongly decreasing (increasing) trend over time, the detrending of the variables around their sample means, for example, leads to an overestimation (underestimation) of the model variables in former (more recent) times and vice versa. To avoid these misspecifications, the trend component of the observable variables is excluded using the Hodrick-Prescott filter.

The extracted cyclical components of the above mentioned time series are linked to the model variables via the following measurement equation:

$$\begin{bmatrix} \Delta GDP_t \\ \Delta CPI_t \\ INT_t \\ \Delta NEER_t \\ \Delta TOT_t \end{bmatrix} = \begin{bmatrix} \Delta y_t \\ 4\pi_t \\ 4R_t \\ \Delta e_t \\ \Delta q_t \end{bmatrix}. \tag{2.16}$$

Dependent on the availability of the time series, the estimation sample ranges from 1994 till 2013 for Poland and the Czech Republic and from 1993 till 2013 for Hungary.

2.3.3 Priors

The choice of priors and standard deviations of shocks (Table 2.2) is guided by Lubik and Schorfheide (2007) and the methodologies described therein. For the price rigidity parameter κ and the intertemporal substitution elasticity parameter τ the prior means are both set at .5 with large standard deviations respectively. The latter is restricted to the interval from 0 to 1 to avoid singularity at $\tau = 1$. Identical priors are also set for the steady state interest rate $\bar{R}$ that is linked to the discount factor β according to $\beta = exp(-\bar{R}/400)$ at a mean of 2.5 and a standard deviation of 1. Priors for the import shares are set so as to match the respective ratios of imports to GDP over the sample. For the Czech Republic and Hungary (.6 and .7) these are nearly twice as large as the Polish equivalent (.35). Based on domestic inflation, the NEER, and a corresponding real effective exchange rate time series, foreign inflation is approximated for all three economies. Estimates for their AR(1) coefficients are then considered to form prior beliefs for ρ_{π^*}. They are centered at .2 with a standard deviation of .1. The shock innovations for the foreign inflation AR process range from 2.3 for the Czech Republic to 4.1 for Poland. Priors for the foreign output coefficients and innovations are based on AR(1) estimates of the ratios of euro area to domestic GDP. Obtaining values between .70 and .88, a common prior mean of .8 with a standard deviation of .1 is chosen. The same applies for the innovation to the foreign output AR process whose priors are centered around .4. Equivalently, priors are set for the technology and the terms of trade processes, by fitting AR(1) processes to the domestic output growth rate and to the observed changes in the terms of trade, respectively. By that, significant differences between the three economies are revealed for the innovations in the terms of trade equation leading to respective prior means from .7 for Hungary to 3.2 for Poland. All of the other values fall into a narrow range, so that the respective priors are assumed to be characterized by identical means and standard deviations around those estimates.

Standard priors are chosen for the parameters of the monetary policy rule: the priors for the reaction parameter to inflation is centered around 1.5, the other two around .5, whereas the prior means for the AR coefficient are set to .5. For all of the aforementioned parameters, sufficiently large standard deviations are chosen. Finally, the priors for the transition probabilities are set in a way to allow for multiple backward and forward regime switches.

2.4 Results

2.4.1 Regime identification

A comparison of the log marginal data densities of the estimated model specifications points at the inferiority of the time-invariant parameters model compared to most of the regime switching specifications (Table 2.1). However, in all three economies model M_1, allowing for switches in the parameters of the policy rule only, fits the observed data even worse. To put it different, models that feature regime switching shocks outperform those that assume time-invariance in the severity of disturbances hitting the economy. For all three economies Model M_2 fits the data best. Models in which all parameters are allowed to switch perform

		Czech Rep.	Hungary	Poland
Time invariant	M_0	-664.50	-616.54	-740.74
Policy parameters only	M_1	-670.21	-618.64	-756.92
Volatility only	M_2	**-567.34**	**-606.04**	**-700.58**
Policy parameters and volatility (one chain)	M_3	-574.97	-615.10	-710.30
Policy parameters and volatility (two chains)	M_4	-580.49	-616.19	-717.97

Table 2.1: Log marginal data densities of different model specifications

significantly worse in all three economies and are thus ignored in the further analyses and interpretations.

Czech Republic For the Czech Republic the estimation reveals periods of different monetary policy regimes as well as episodes of high and low volatility (Figure 2.1). As concerns the monetary policy, it is characterized by high responses to movements of either the exchange rate or the inflation rate and a lower attention to the other target variable respectively (Table 2.3). The smoothed probabilities of being in the high exchange rate response regime suggest, in two out of three specifications, that a switch to the low response regime occurred in the middle of 1997. This finding nearly perfectly matches the abandonment of the exchange rate peg at the end of May of that year. In addition, slightly lower probabilities of being in the high response regime in the year before reflect the widening of the koruna's fluctuation band and the consequential lower consideration of its movements in the conduct of monetary policy.

Since the policy switch the CNB has continuously been operating in the low exchange rate/high inflation response regime. In the single chain specification M_3 that suggests a switch back to the former policy strategy during the most recent financial crisis, regime probabilities seem to be rather driven by the identification of different regimes of the shock volatilities. One indication for this is the finding that the smoothed probabilities of being in the high volatility regime are virtually independent of the model setup and thus regardless of the consideration of different policy regimes. In addition, the estimate for the error term in the interest rate rule in M_3 is much higher in the high compared to the low volatility regime, with the difference being larger than in any other model setup. Hence, model

M_3 possibly fails to correctly account for changes in the monetary policy rule. Instead, systematic reactions in the high exchange rate response regime seem to be partly declared as policy disturbances. One potential explanation for this could be the relatively short period of the former compared to the current policy strategy. Estimation results of the

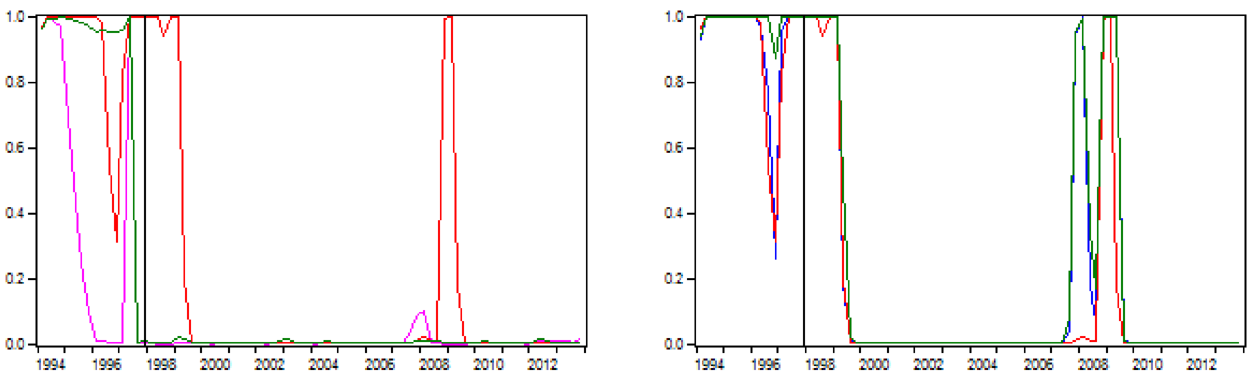

Figure 2.1: Smoothed regime probabilities in the Czech Republic for the high exchange rate response (left) and high volatility regime (right) according to M_1 (magenta), M_2 (blue), M_3 (red), and M_4 (green). The black vertical line marks the official introduction of inflation targeting.

specification M_4, according to which switches of the policy parameters and shock volatilities are governed by independent Markov chains, suggest the reactions of the CNB to movements of the exchange rate and output to have decreased remarkably and to be almost negligible under the present policy strategy. On the other hand and apart from an increased attention to the inflation rate, the degree of interest rate smoothing is nearly twice as large as under the former exchange rate targeting regime.

Volatilities of shocks that hit the Czech economy also vary substantially between the two identified regimes. Except for the foreign inflation shock, these are on average four times larger in the more turbulent environment. According to the smoothed probabilities, it has prevailed until the end of the Russian crisis of 1998 and thus throughout most of the 1990s. Apart from the financial crisis that started to erupt in 2007, the Czech Republic has remained in the low volatility regime since then. This overall higher persistence of the current volatility regime compared to its former counterpart is expressed in a lower transition probability. Even more persistent, by four times compared to the previous regime, is the current monetary policy strategy.

Hungary For Hungary the estimation identifies switches between different monetary policy strategies as well as high and low volatility regimes (Figure 2.2). Following the results, there have in general been smaller disturbances to the economy since 1996, when abstracting from the Russian crisis of 1998, the recent financial turmoil, and three domestic crises or speculative attacks on the forint. Compared to the other economies, the difference between the values of the shock coefficients in the two regimes is lower in Hungary (Table 2.4). Periods of strong and weak responses to exchange rate movements are also well identified for the specifications in which the policy parameters are allowed to switch independently of the shock variances. As in the Czech case, M_3 seems to partly attribute systematic policy changes to the error term. In general, periods of low volatility go along with a more aggressive reaction to inflation and also to the exchange rate. This does not come surprisingly, since Hungary has continued to manage is exchange rate despite having switched its target from the exchange rate to inflation. Thus, the left graphs in Figure 2.2 rather show switches in the monetary policy in general and hence the probabilities of being in the more recent inflation targeting regime. Abstracting from the smoothed probabilities implied by the rather volatility driven changes in M_3 and the countering of appreciation pressures and speculative attacks in 2002 and 2003, the MNB has maintained its policy strategy since the official introduction of inflation targeting in 2001. Its reaction to inflation pressures has strongly increased compared to the very low coefficient value in the former regime. The interest rate smoothing parameter is also around twice as large in the policy in place.

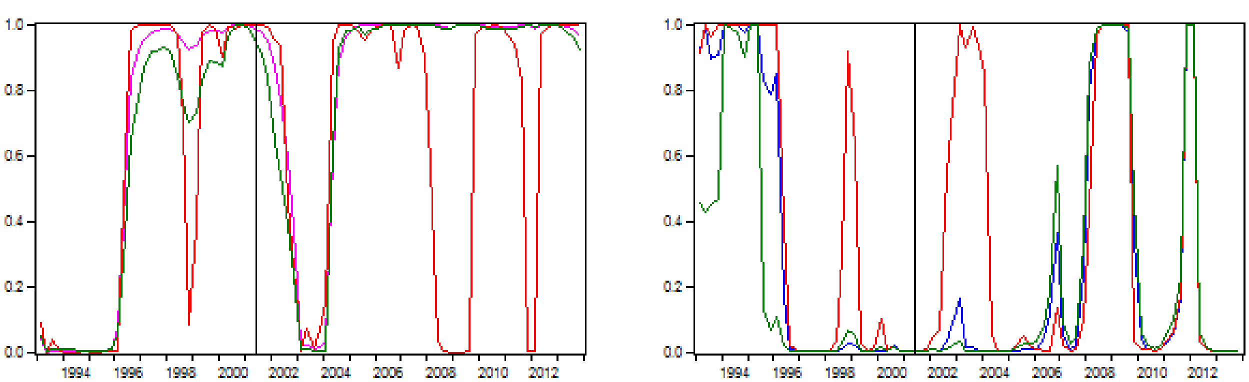

Figure 2.2: Smoothed regime probabilities in Hungary for the high exchange rate response (left) and high volatility regime (right) according to M_1 (magenta), M_2 (blue), M_3 (red), and M_4 (green). The black vertical line marks the official introduction of inflation targeting.

Poland For Poland the estimation reveals clear switches between high and low volatility regimes, independently of the model employed (Figure 2.3). Since 2002 Poland has experienced a rather calm macroeconomic environment. Estimations further suggest, that a regime switch in the monetary policy took place around 1996 and hence prior to the official introduction of inflation targeting at the beginning of 1998. After the switch, periods of strong appreciations of the zloty following the accession to the European Union that led to interventions of the NBP are well identified by slightly higher probabilities of the old regime based on M_3 and a high volatility occurrence. Nevertheless, the extent to which the central bank reacted to variations in the currency price is very low in both regimes (Table 2.5).

Following the regime switch, the coefficient for inflation in the policy rule clearly increased, especially in the model specifications in which the policy parameters are allowed to switch independently. The opposite holds true for the output coefficient, which is smaller

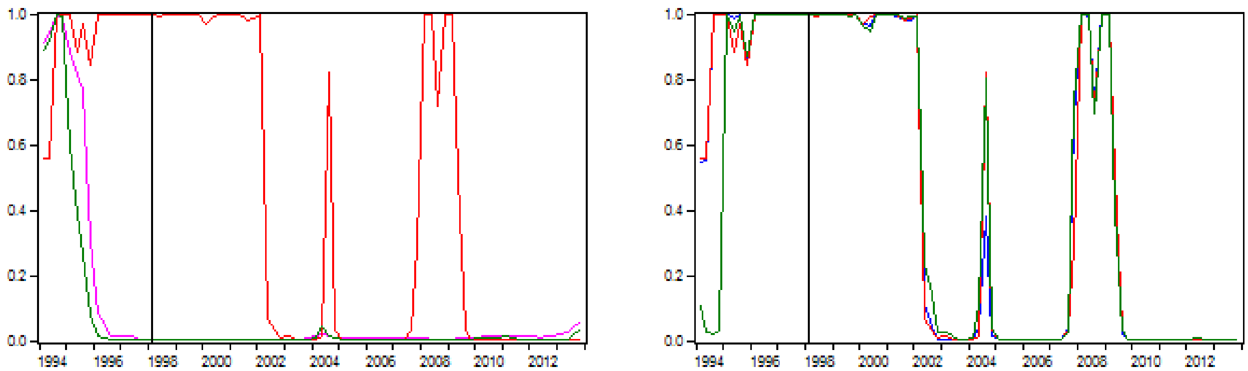

Figure 2.3: Smoothed regime probabilities in Poland for the high exchange rate response (left) and high volatility regime (right) according to M_1 (magenta), M_2 (blue), M_3 (red), and M_4 (green). The black vertical line marks the official introduction of inflation targeting.

under the new regime. The implied smoothed probabilities for the Polish economy being in a high volatility regime are nearly identical throughout the different models, suggesting changes in the standard deviations of shocks rather than of policy parameters being the main drivers of the estimated regime switches in M_3. In particular, this seems to apply to the recent financial crisis, in which the NBP is estimated to have maintained its policy strategy according to M_4 and also M_1.

2.4.2 Policy evaluation

After periods of low output growth and high inflation rates in the three economies during the 1990s, the former have increased whereas inflation rates have come down to levels only slightly above targets in advanced economies. At the same time, the volatilities of both variables markedly decreased following the official implementation of inflation targeting. One potential factor among others could have been a better performing monetary policy due to an increased experience and a higher credibility. Following this, private sector expectations of price level movements are expected to have increasingly mirrored the central banks' targets and by that substantially facilitated the achievement of the latter. On the other hand, a less volatile macroeconomic environment could have led to the observed success in the evolution of targeted variables. This factor seems to be particularly relevant for the highly open economies of the Czech Republic and Hungary. With exports and imports amounting to roughly two thirds of the respective GDP, they are strongly affected by foreign disturbances.

As the estimation results reveal, in all three economies the volatilities of shocks have decreased over time and by that facilitated the monetary policies under the nearly coexisting current strategies. Thus, for a correct assessment of their performances, the different underlying environments have to be correctly accounted for. Therefore, simulations are conducted for different combinations of policy and volatility regimes. As a benchmark serves the current monetary policy facing the current small-sized shocks to foreign output, foreign inflation, the terms of trade, and technology. The impacts of disturbances on the volatilities of target variables are quantified and compared to a scenario in which the current policy is confronted with the former highly volatile environment (scenario 1), a setup in which the old monetary policy regime faces the lower disturbances of the more recent years (Scenario 2), and the old policy in the former high volatility environment (scenario 3).

To accurately account for policy changes and the regimes of high and low volatility, the three economies are analyzed based on the estimations of the model specification M_4 in which policy and volatility switches occur independently from each other. Shocks and model parameters, including the coefficients of the monetary policy rule, are set to their respective posterior modes. The calibrated models are simulated over 10,000 periods, dropping the first 3,000 observations.

Based on the simulation results, the extents to which the monetary authorities' efforts ('good policy') and the smoother macroeconomic environment ('good luck') have contributed to the favorable development of target variables are assessed. A central bank is considered having rather had 'good luck' in the case of the old policy strategy being at least as effective as the strategy in place when facing the same environment. This requires shock impacts on the variables considered (output, inflation, interest rate, and nominal exchange rate depreciation) to be larger in the benchmark case (scenario 1) compared to scenario 2 (scenario 3). Lower effects in the benchmark case relative to scenario 2, as well as scenario 1 relative to scenario 3, would point at a 'good policy' with the more recent regime being able to better handle disturbances of the same intensity. In addition, 'good policy' is also attributed to a central bank if its current strategy is more effective than the former one, even in a more volatile environment. This holds true, if shock impacts are lower in scenario 1 compared to scenario

2. Finally, since all three central banks have retained their policy regimes during the high volatility periods of the recent financial crisis according to the estimations of most of the specifications, a higher effectiveness of scenario 1 compared to scenario 3 would also point at a correct policy decision in this respect.

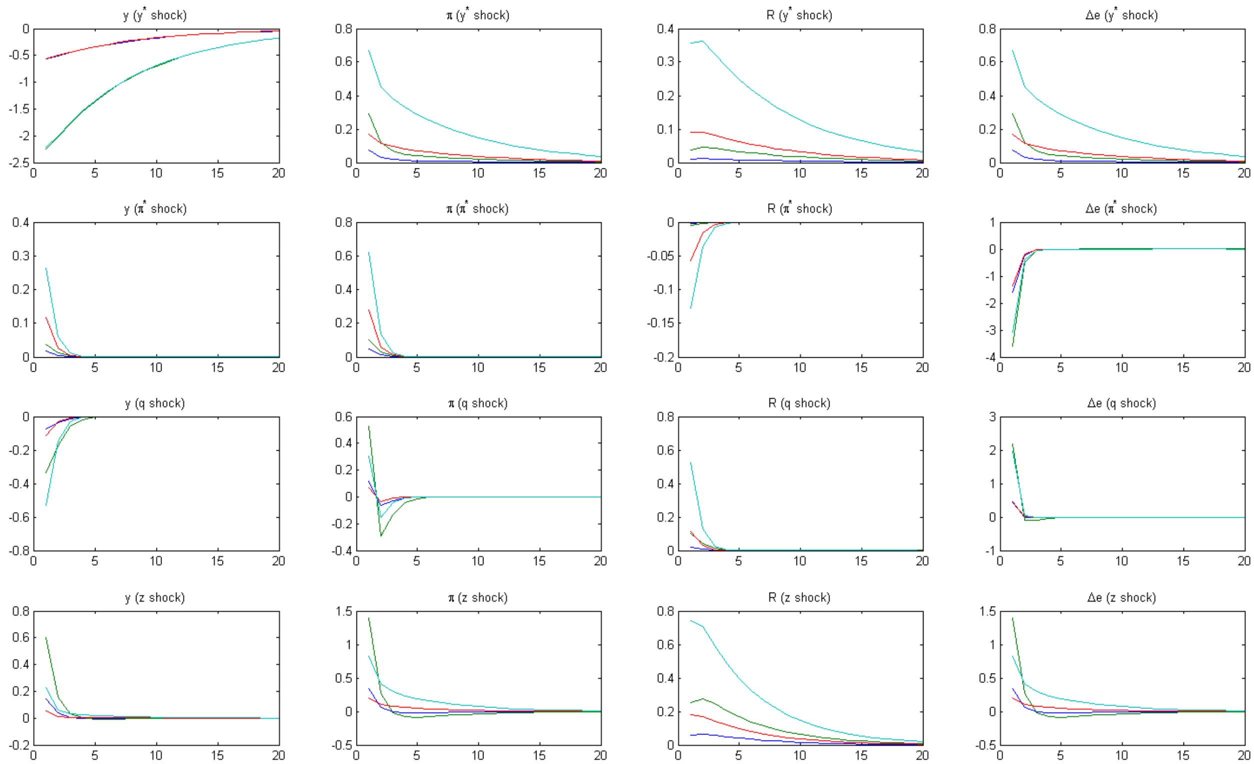

Figure 2.4: Impulse responses for the Czech Republic to one-standard deviation shocks. Figure depicts the actual policy and volatility (blue), actual policy and high volatility (green), former policy and low volatility (red), and former policy and high volatility (cyan).

Czech Republic Impulse responses for the Czech Republic are presented in Figure 2.4. In the presence of shocks to foreign output and inflation, the impact on most domestic variables is lower under the current low exchange rate response regime (Table 2.6). In all but two cases, the current strategy clearly outperforms the previous rule providing evidence of 'good policy' rather than 'good luck' to have been responsible for the reduction in the respective volatilities. Following foreign inflation shocks, this finding holds true even if the current policy operates in the high volatility environment, with the impact on the variables of interest being lower compared to the former policy in modest times. Exceptions to the superiority of the regime in place form the impact of a foreign output shock on domestic output that is nearly identical for both strategies and the effect of foreign inflation shocks on the exchange rate. Since the simulation results do not suggest a higher effectiveness of the old policy regime in the high volatility setup, the CNB has most likely prevented a larger transmission of foreign shocks to domestic output and inflation by maintaining its strategy during the most recent financial crisis

The effects of terms of trade shocks on output and inflation are mixed. Whereas output is less affected by terms of trade shocks under the more recent regime, the opposite holds true for domestic inflation. Innovations to technology have a larger impact on domestic output, reflecting the only marginal consideration of the latter in the central bank's policy rule to counteract the disturbance. Domestic inflation is also stronger affected by the technology shock under the current policy, albeit only slightly.

Not surprisingly, the higher degree of interest rate smoothing under the current regime results in a remarkably lower effect of all considered shocks on the interest rate. Finally, assuming a preference for some exchange rate stability, the more recent low exchange rate response regime performs at least nearly as good as the high response regime in the presence of all considered shocks.

Hungary In Hungary, the current monetary policy regime is also characterized by a remarkably lower impact of foreign output shocks on inflation, the interest rate, and the exchange rate (Figure 2.5 and Table 2.7). In this context, the policy in place outperforms the former strategy even in a more volatile environment. However, the impact on output given the same magnitude of shocks is larger than under the former regime. The effects of foreign inflation shocks on domestic output and inflation are nearly the same under both policy strategies. Hence, compared to the Czech Republic, there is less clear evidence for the policy in place to have been more effective than the old regime in reducing the effects of equal size external disturbances on target variables. At the same time, the current policy does not prove to be inferior to the former strategy, except for the vulnerability of domestic output to foreign output shocks. Regardless of the inconclusive evaluation of the monetary policy, a smoother macroeconomic environment appears to have considerably facilitated the central bank's efforts following the official implementation of inflation targeting. However, this finding holds true only for the two clearly external disturbances to foreign output and inflation. In the presence of terms of trade shocks, the current regime performs better when evaluated on the basis of the effects on domestic inflation and only slightly worse with regard to output fluctuations.

In addition, output and inflation are less affected by technology shocks of either intensity under the policy in place. In this context, the current strategy performs better even in

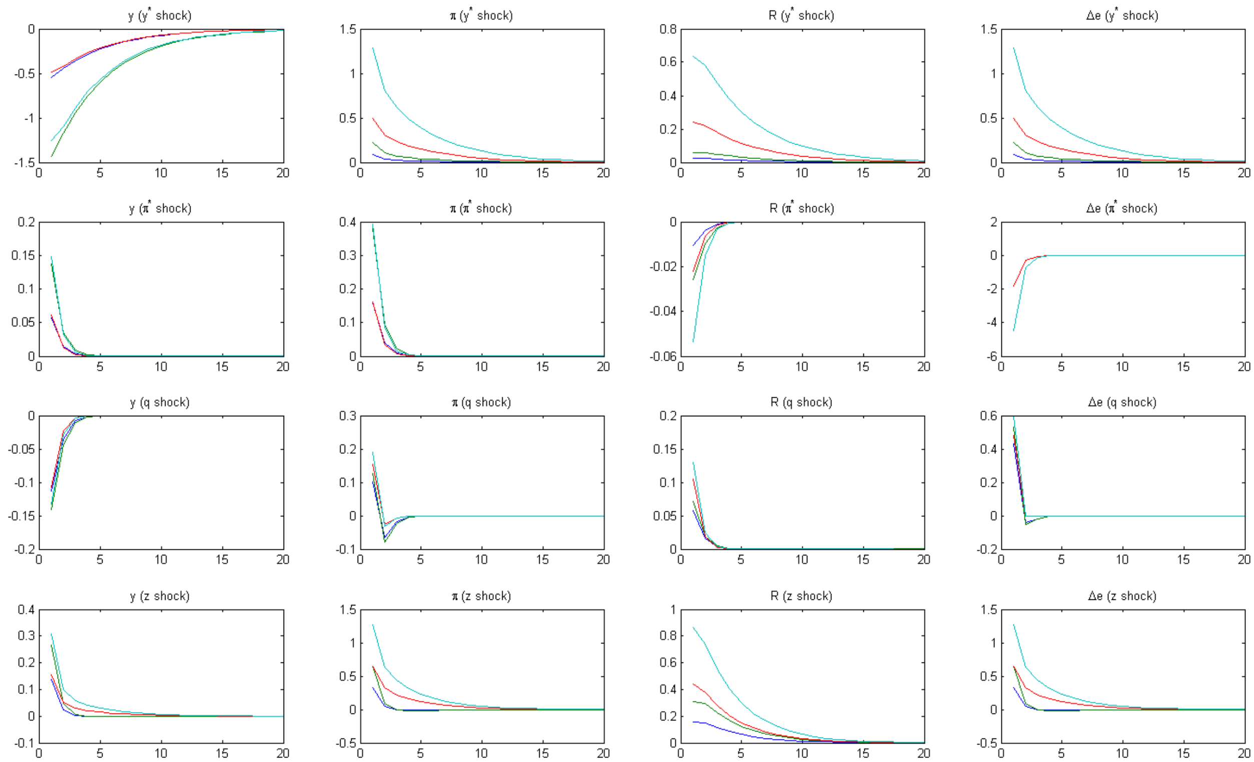

Figure 2.5: Impulse responses for Hungary to one-standard deviation shocks. Figure depicts the actual policy and volatility (blue), actual policy and high volatility (green), former policy and low volatility (red), and former policy and high volatility (cyan).

a higher volatility environment. Finally, a much higher degree of interest rate smoothing has lead to substantially lower effects of all shocks on the interest rate, while the increased attention to exchange rate movements has reduced the impact of all disturbances, except for the foreign inflation shock, under the current policy regime.

Poland Simulations for Poland reveal a clear superiority of the policy regime in place compared to its former counterpart (Figure 2.6 and Table 2.8). Except for the slightly stronger effect of a foreign output shock on domestic output, the impacts of all disturbances on output and inflation are lower under the more recent strategy, hinting at the Polish central bank to have realized a 'good policy' in the aftermath of the regime switch. With regard to foreign inflation shocks, the current policy outperforms the former one even in a more turbulent environment. The same holds true for the effects of foreign output disturbances on domestic inflation. The results thus suggest that by not altering its policy during the recent financial crisis, the NBP reduced the transmission of foreign shocks to domestic variables compared to the alternative former regime.

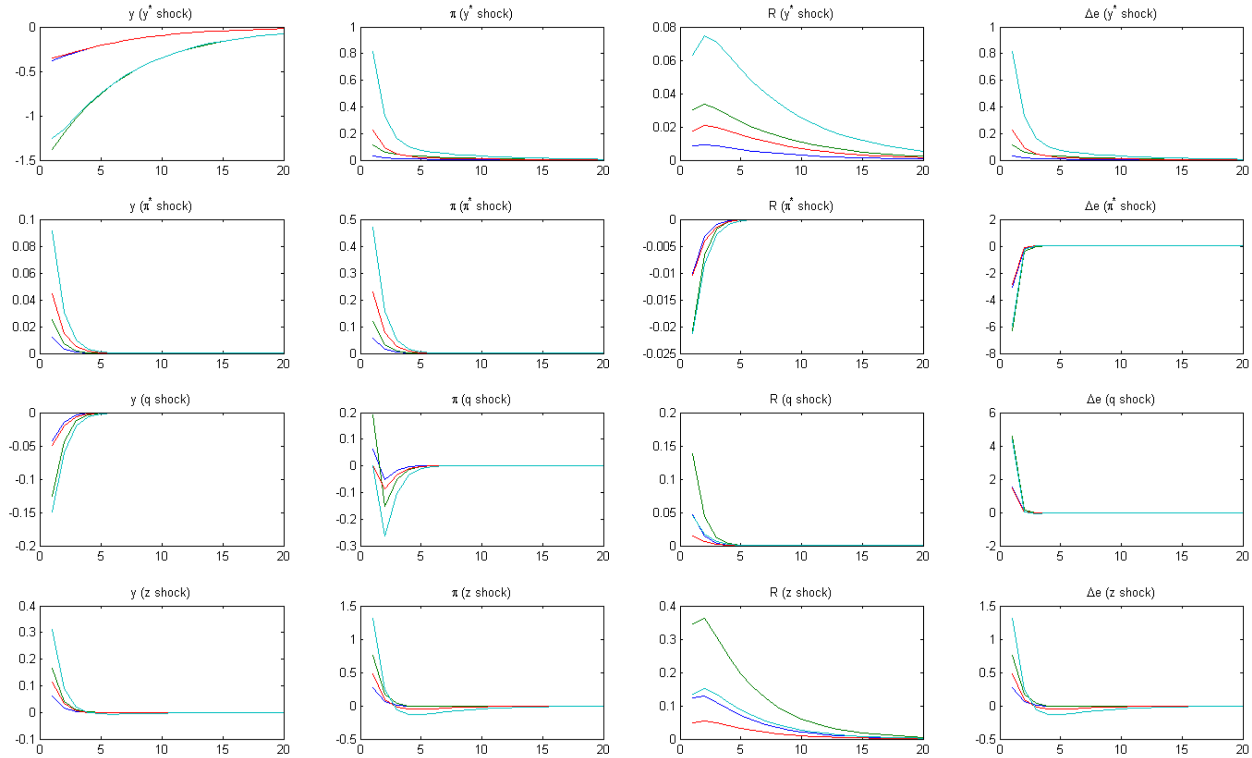

Figure 2.6: Impulse responses for Poland to one-standard deviation shocks. Figure depicts the actual policy and volatility (blue), actual policy and high volatility (green), former policy and low volatility (red), and former policy and high volatility (cyan).

In contrast to the other two economies considered, the Polish central bank is estimated to have lowered the degree of interest rate smoothing following the regime switch. Consequently, the interest rate shows stronger reactions to equal size shocks in most of the cases. Similar to the Czech Republic, the reduced consideration of the exchange rate in the central bank's reaction function does not result in substantially higher shock effects under the current low exchange rate response regime.

2.5 Conclusion

In a simple Markov-switching small open economy framework this work analyzes possible switches in the monetary policy regimes of the Czech Republic, Hungary, and Poland following the implementation of inflation rather than exchange rate targeting as their policy strategy. For the Czech Republic and Poland the estimation reveals switches from high to low exchange rate response regimes that go along with a reduction in the volatility of shocks and a more prominent consideration of inflation in the central banks' policy rules. In both economies the switches implied by the smoothed state probabilities occurred shortly before the official introduction of inflation targeting. In Hungary, on the other hand, the central bank is estimated to have increased its response to exchange rate movements after the introduction of the new strategy. This finding reflects the ongoing managing of the forint's rate over the regarded sample and despite the repeal of exchange rate targeting. Analogously to the other two economies, the consideration of the inflation rate in the policy rule increased, whereas the volatilities of shocks remarkably declined.

Simulations of the model calibrated to allow the different policy strategies to operate under identical conditions characterized by equal size shocks also point at the success of monetary policy in the Czech Republic and Poland in stabilizing output growth and inflation in the recent years rather than this outcome being the result of a less volatile macroeconomic environment. In Hungary, the reduction in the volatilities of target variables is to a larger extent also attributable to the decrease in the magnitude of external disturbances.

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Appendix A: Tables

		Czech Rep.		Hungary		Poland	
	Dens.	Mean	S.d.	Mean	S.d.	Mean	S.d.
$\bar{R}$	G	2.50	1.00	2.50	1.00	2.50	1.00
α	B	0.60	0.10	0.70	0.15	0.35	0.10
τ	B	0.50	0.20	0.50	0.20	0.50	0.20
κ	G	0.50	0.25	0.50	0.25	0.50	0.25
ψ_1	G	1.50	0.50	1.50	0.50	1.50	0.50
ψ_2	G	0.25	0.15	0.25	0.15	0.25	0.15
ψ_3	G	0.25	0.15	0.25	0.15	0.25	0.15
ρ_R	B	0.50	0.25	0.50	0.25	0.50	0.25
ρ_q	B	0.30	0.15	0.30	0.15	0.30	0.15
ρ_z	B	0.30	0.15	0.30	0.15	0.30	0.50
ρ_{y^*}	B	0.80	0.10	0.80	0.10	0.80	0.10
ρ_{π^*}	B	0.20	0.10	0.20	0.10	0.20	0.10
σ_R	InvG	0.50	4.00	0.50	4.00	0.50	4.00
σ_q	InvG	1.30	4.00	0.70	4.00	3.20	4.00
σ_z	InvG	1.00	4.00	1.00	4.00	1.00	4.00
σ_{y^*}	InvG	0.40	4.00	0.40	4.00	0.40	4.00
σ_{π^*}	InvG	2.30	4.00	2.70	4.00	4.10	4.00
P_{12}	B	0.10	0.05	0.10	0.05	0.10	0.05
P_{21}	B	0.10	0.05	0.10	0.05	0.10	0.05
Q_{12}	B	0.10	0.05	0.10	0.05	0.10	0.05
Q_{21}	B	0.10	0.05	0.10	0.05	0.10	0.05

Table 2.2: Prior distributions

	M_0		M_1				M_2				M_3				M_4			
	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.
R	2.0921	0.0115	2.0899	0.0099			2.0883	0.0083			2.0903	0.0068			2.0874	0.0075		
α	0.4990	0.0086	0.5012	0.0072			0.4983	0.0060			0.5107	0.0049			0.4980	0.0053		
τ	0.1030	0.0047	0.1054	0.0037			0.1120	0.0031			0.1152	0.0027			0.1135	0.0028		
κ	2.1199	0.0123	2.1210	0.0105			1.4334	0.0071			1.5735	0.0060			1.4389	0.0064		
ψ_1	1.3776	0.0099	0.7133	0.0074	1.4372	0.0086	1.7514	0.0075			1.5353	0.0059	1.6262	0.0060	1.2890	0.0060	1.6979	0.0067
ψ_2	0.0860	0.0089	0.0940	0.0077	0.0963	0.0077	0.0632	0.0058			0.3097	0.0049	0.0223	0.0040	0.1904	0.0054	0.0564	0.0052
ψ_3	0.1350	0.0090	0.3032	0.0078	0.0818	0.0076	0.0626	0.0059			0.1568	0.0049	0.0930	0.0048	0.3550	0.0053	0.0607	0.0053
ρ_R	0.6580	0.0082	0.1752	0.0074	0.7865	0.0060	0.8739	0.0037			0.6418	0.0049	0.9084	0.0026	0.4696	0.0054	0.8988	0.0028
ρ_q	0.0367	0.0089	0.0360	0.0075			0.0978	0.0060			0.0522	0.0049			0.1135	0.0054		
ρ_z	0.6796	0.0069	0.7514	0.0054			0.8140	0.0048			0.8525	0.0037			0.8172	0.0042		
ρ_{y^*}	0.7355	0.0086	0.7180	0.0074			0.8852	0.0060			0.9060	0.0048			0.8743	0.0054		
ρ_{π^*}	0.1289	0.0087	0.1322	0.0074			0.1712	0.0060			0.1362	0.0049			0.1426	0.0054		
σ_R	0.3864	0.0086	0.2583	0.0066			0.4999	0.0060	0.0933	0.0035	0.6949	0.0048	0.0764	0.0026	0.4356	0.0054	0.0748	0.0025
σ_q	1.7250	0.0109	1.7262	0.0094			3.3459	0.0105	0.7160	0.0060	3.4729	0.0088	0.7683	0.0049	3.2735	0.0094	0.7059	0.0054
σ_z	0.4853	0.0087	0.3278	0.0071			0.7903	0.0059	0.1621	0.0051	0.6484	0.0049	0.1369	0.0040	0.6740	0.0054	0.1619	0.0045
σ_{y^*}	0.2136	0.0083	0.2180	0.0072			0.4094	0.0062	0.0985	0.0037	0.4350	0.0049	0.0985	0.0030	0.3999	0.0055	0.1004	0.0033
σ_{π^*}	2.5808	0.0131	2.5786	0.0113			3.7892	0.0112	1.6456	0.0075	3.5919	0.0089	1.9656	0.0067	3.7079	0.0100	1.6553	0.0068
p_{12}			0.0770	0.0076							0.0981	0.0049			0.0944	0.0054		
p_{21}			0.0286	0.0056							0.0314	0.0042			0.0242	0.0042		
q_{12}							0.1049	0.0061							0.0908	0.0054		
q_{21}							0.0614	0.0059							0.0542	0.0051		

Table 2.3: Posterior modes for the Czech Republic For the models M_1, M_2, M_3, and M_4 the results in the right two columns refer to the high exchange rate response or high volatility regime respectively.

	M_0		M_1				M_2				M_3				M_4			
	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.
R	2.0918	0.0127	2.0911	0.0112			2.0906	0.0116			2.0898	0.0111			2.0903	0.0106		
α	0.6006	0.0095	0.5768	0.0083			0.5755	0.0086			0.5713	0.0082			0.5697	0.0078		
τ	0.1501	0.0048	0.1451	0.0041			0.1406	0.0038			0.1417	0.0036			0.1356	0.0033		
κ	1.6435	0.0119	1.3509	0.0096			1.8804	0.0114			1.6164	0.0102			1.7561	0.0102		
ψ_1	1.2130	0.0101	2.1290	0.0115	0.7825	0.0086	1.3711	0.0096			1.9539	0.0109	1.0402	0.0082	2.0707	0.0107	0.8727	0.0078
ψ_2	0.1497	0.0098	0.2115	0.0085	0.3589	0.0086	0.1205	0.0088			0.1116	0.0084	0.1856	0.0084	0.1549	0.0080	0.2377	0.0079
ψ_3	0.1228	0.0093	0.2157	0.0086	0.0756	0.0084	0.1440	0.0085			0.1854	0.0082	0.1078	0.0082	0.2093	0.0079	0.1054	0.0079
ρ_R	0.6170	0.0086	0.8178	0.0063	0.3357	0.0085	0.6544	0.0071			0.8252	0.0053	0.4312	0.0083	0.7950	0.0055	0.3605	0.0079
ρ_q	0.0707	0.0099	0.0733	0.0087			0.0686	0.0089			0.0768	0.0085			0.0688	0.0081		
ρ_z	0.7933	0.0065	0.7858	0.0061			0.7500	0.0060			0.7934	0.0058			0.7344	0.0056		
ρ_{y^*}	0.8037	0.0098	0.7273	0.0088			0.8219	0.0087			0.8156	0.0084			0.7978	0.0080		
ρ_{π^*}	0.1543	0.0095	0.1668	0.0084			0.1848	0.0086			0.1719	0.0083			0.1662	0.0079		
σ_R	0.3630	0.0091	0.2884	0.0073			0.5244	0.0084	0.2829	0.0076	0.1829	0.0059	0.5397	0.0082	0.4654	0.0078	0.2589	0.0065
σ_q	0.8218	0.0096	0.8222	0.0085			0.9673	0.0082	0.7392	0.0085	0.7210	0.0082	0.9482	0.0080	0.9424	0.0076	0.7627	0.0079
σ_z	0.3501	0.0086	0.3670	0.0079			0.7222	0.0082	0.3157	0.0081	0.2679	0.0078	0.5104	0.0081	0.6559	0.0076	0.3343	0.0075
σ_{y^*}	0.1941	0.0066	0.1952	0.0057			0.2898	0.0093	0.1083	0.0039	0.1122	0.0040	0.2645	0.0086	0.2868	0.0083	0.1093	0.0033
σ_{π^*}	3.0325	0.0159	3.0301	0.0142			4.5793	0.0173	2.0466	0.0118	2.0860	0.0115	4.1136	0.0159	4.8764	0.0164	2.0139	0.0108
p_{12}			0.0377	0.0065							0.0775	0.0074			0.0425	0.0059		
p_{21}			0.0778	0.0083							0.1160	0.0080			0.0801	0.0073		
q_{12}							0.1105	0.0087							0.1240	0.0079		
q_{21}							0.0588	0.0078							0.0630	0.0070		

Table 2.4: Posterior modes for Hungary For the models M_1, M_2, M_3, and M_4 the results in the right two columns refer to the high exchange rate response or high volatility regime respectively.

	M_0		M_1				M_2				M_3				M_4			
	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.	Mode	S.d.
R	2.0927	0.0074	2.0924	0.0070			2.0926	0.0073			2.0928	0.0071			2.0924	0.0075		
α	0.1564	0.0051	0.1536	0.0044			0.1502	0.0040			0.1561	0.0038			0.1588	0.0038		
τ	0.0540	0.0039	0.0529	0.0032			0.0636	0.0025			0.0679	0.0023			0.0704	0.0024		
κ	1.2080	0.0065	1.2566	0.0061			0.9743	0.0054			0.9033	0.0052			1.1775	0.0060		
ψ_1	2.0998	0.0078	1.3026	0.0061	2.3458	0.0077	2.0940	0.0074			1.8563	0.0069	2.0329	0.0071	1.1927	0.0059	2.3167	0.0080
ψ_2	0.1569	0.0061	0.2078	0.0056	0.1164	0.0056	0.0957	0.0055			0.2377	0.0053	0.0694	0.0053	0.1964	0.0055	0.0786	0.0057
ψ_3	0.0611	0.0060	0.1520	0.0055	0.0643	0.0054	0.0557	0.0053			0.0691	0.0054	0.0604	0.0053	0.1457	0.0055	0.0619	0.0055
ρ_R	0.7766	0.0052	0.8820	0.0055	0.7647	0.0048	0.8376	0.0040			0.7413	0.0052	0.8826	0.0037	0.9258	0.0050	0.8079	0.0043
ρ_q	0.0549	0.0060	0.0569	0.0056			0.0641	0.0055			0.0674	0.0054			0.0613	0.0057		
ρ_z	0.7599	0.0055	0.7482	0.0050			0.7942	0.0047			0.8043	0.0044			0.7880	0.0047		
ρ_{y^*}	0.7227	0.0058	0.7357	0.0054			0.8515	0.0055			0.8564	0.0054			0.8569	0.0057		
ρ_{π^*}	0.0773	0.0059	0.0743	0.0055			0.0723	0.0055			0.0729	0.0053			0.0665	0.0056		
σ_R	0.2952	0.0057	0.2747	0.0052			0.3436	0.0054	0.1176	0.0042	0.3889	0.0053	0.0901	0.0033	0.3143	0.0056	0.1632	0.0047
σ_q	3.8202	0.0100	3.8215	0.0095			5.0930	0.0114	1.8137	0.0069	5.1343	0.0112	1.7311	0.0066	5.2095	0.0119	1.7377	0.0070
σ_z	0.4720	0.0058	0.5088	0.0054			0.6260	0.0053	0.2427	0.0053	0.5784	0.0052	0.2443	0.0051	0.6777	0.0054	0.2444	0.0055
σ_{y^*}	0.1905	0.0062	0.1896	0.0052			0.3341	0.0056	0.0994	0.0043	0.3504	0.0055	0.0997	0.0040	0.3624	0.0058	0.0998	0.0038
σ_{π^*}	5.0125	0.0112	5.0177	0.0107			6.3138	0.0126	3.1826	0.0090	6.2696	0.0124	3.2308	0.0089	6.4105	0.0132	3.1168	0.0093
p_{12}			0.0854	0.0053							0.0863	0.0053			0.0915	0.0055		
p_{21}			0.0288	0.0051							0.0661	0.0052			0.0299	0.0045		
q_{12}							0.0773	0.0054							0.0883	0.0056		
q_{21}							0.0678	0.0054							0.0780	0.0055		

Table 2.5: Posterior modes for Poland For the models M_1, M_2, M_3, and M_4 the results in the right two columns refer to the high exchange rate response or high volatility regime respectively.

	Low volatility		High volatility	
	Current policy	Former policy	Current policy	Former policy
		ϵ^{y^*}		
y	1.1735	1.1609	4.6740	4.6241
π	0.0831	0.2770	0.3309	1.1035
R	0.0263	0.2075	0.1046	0.8263
Δe	0.0831	0.2770	0.3309	1.1035
		ϵ^{π^*}		
y	0.0179	0.1199	0.0401	0.2686
π	0.0471	0.2828	0.1054	0.6336
R	0.0022	0.0592	0.0050	0.1326
Δe	1.6106	1.3752	3.6078	3.0804
		ϵ^{q}		
y	0.0832	0.1185	0.3858	0.5496
π	0.1309	0.0732	0.6072	0.3393
R	0.0239	0.1158	0.1106	0.5372
Δe	0.4630	0.4155	2.1471	1.9266
		ϵ^{z}		
y	0.1492	0.0574	0.6212	0.2391
π	0.3413	0.2500	1.4210	1.0410
R	0.1367	0.3477	0.5691	1.4475
Δe	0.3413	0.2500	1.4210	1.0410

Table 2.6: Simulated standard deviations of model variables following one-standard deviation shocks in the Czech Republic

	Low volatility		High volatility	
	Current policy	Former policy	Current policy	Former policy
		ϵ^{y^*}		
y	0.9199	0.8455	2.4137	2.2185
π	0.1023	0.6933	0.2684	1.8192
R	0.0443	0.4434	0.1162	1.1634
Δe	0.1023	0.6933	0.2684	1.8192
		ϵ^{π^*}		
y	0.0584	0.0620	0.1413	0.1502
π	0.1622	0.1645	0.3927	0.3982
R	0.0115	0.0229	0.0277	0.0554
Δe	1.8634	1.8606	4.5119	4.5053
		ϵ^{q}		
y	0.1189	0.1093	0.1469	0.1350
π	0.1199	0.1537	0.1481	0.1899
R	0.0600	0.1060	0.0742	0.1310
Δe	0.4261	0.4760	0.5265	0.5881
		ϵ^{z}		
y	0.1375	0.1688	0.2697	0.3312
π	0.3318	0.7921	0.6509	1.5542
R	0.2783	0.7155	0.5460	1.4039
Δe	0.3318	0.7921	0.6509	1.5542

Table 2.7: Simulated standard deviations of model variables following one-standard deviation shocks in Hungary

	Low volatility		High volatility	
	Current policy	Former policy	Current policy	Former policy
		ϵ^{y^*}		
y	0.7351	0.7096	2.6695	2.5768
π	0.0404	0.2507	0.1467	0.9104
R	0.0207	0.0470	0.0751	0.1707
Δe	0.0404	0.2507	0.1467	0.9104
		ϵ^{π^*}		
y	0.0128	0.0469	0.0264	0.0965
π	0.0605	0.2411	0.1245	0.4959
R	0.0106	0.0112	0.0219	0.0231
Δe	3.0297	2.8575	6.2313	5.8772
		ϵ^{q}		
y	0.0444	0.0542	0.1331	0.1626
π	0.0820	0.0952	0.2457	0.2854
R	0.0482	0.0163	0.1445	0.0488
Δe	1.5074	1.4430	4.5192	4.3259
		ϵ^{z}		
y	0.0619	0.1167	0.1715	0.3235
π	0.2772	0.4907	0.7685	1.3608
R	0.2569	0.1089	0.7124	0.3020
Δe	0.2772	0.4907	0.7685	1.3608

Table 2.8: Simulated standard deviations of model variables following one-standard deviation shocks in Poland

Chapter 3

Monetary Policy in an Oil-Dependent Economy in the Presence of Multiple Shocks

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Abstract

Russian monetary policy has been challenged by large and continuous private capital outflows and a sharp drop in oil prices during 2014, with both ongoings having put a significant depreciation pressure on the ruble and having led the central bank to eventually give up its exchange rate management strategy. Against this background, this chapter estimates a small open economy model for Russia, featuring an oil price sector and extended by a specification of the foreign exchange market to correctly account for systematic central bank interventions. We find that shocks to the oil price and private capital flows substantially affect domestic variables, such as inflation, output and the exchange rate. Simulations of the model for the estimated actual strategy and five alternative regimes suggest that the vulnerability of the Russian economy to external shocks can be substantially lowered by adopting some form of inflation targeting strategy. Foreign exchange intervention-based policy strategies to target the nominal exchange rate or the ruble price of oil, on the other hand, prove inferior to the policy in place.

3.1 Introduction

After Russian GDP growth already slowed down in 2013, increased political uncertainty and sanctions have amplified capital outflows and the economic downturn in 2014. In addition, the sharp fall in oil prices in the second half of the year reduced capital inflows and output growth even further. In order to prevent a sharp depreciation of the ruble and an increase in domestic inflation as a result thereof, the central bank raised its key policy rate in six steps by 1150 basis points during 2014. In addition, it directly intervened in the foreign exchange market by selling parts of its currency reserves until it officially allowed the ruble to freely float. Whereas a strong devaluation could not have been prevented and the exchange rate management has been eventually given up, raised interest rates might have posed an additional obstacle for the already weak economy. Against this background, this work aims at analyzing and assessing the monetary policy of the Russian central bank in the presence of simultaneously occurring shocks to the oil price and capital outflows. To correctly account for specific features of the Russian economy, the oil sector as well as foreign exchange interventions via risk-averse dealers are introduced into an small open economy DSGE model estimated for Russia. Simulations are conducted for different alternative policy strategies that are subsequently assessed on the basis of the effects they have on particular variables of interest.

This study adds to the literature on the optimal reaction of monetary policy in the presence of commodity price shocks, in particular for the Russian economy, and the implementation of foreign exchange interventions into dynamic stochastic general equilibrium (DSGE) models. Bernanke et al. (1997) and Gertler et al. (1999) argue that an insufficient monetary policy reaction to oil price shocks amplifies the negative influences of the shock. Their conclusion stems from the empirical evidence of the 1970s when the Federal Reserve raised interest rates to little to curb the impact of the oil price shocks on inflation and inflation expectations. On the other hand, the policy tightening was too strong that it led to adverse implications for the real economy. While these conclusions can be applied to other oil-importing economies, implications on the effects of commodity price shocks and optimal monetary policy would differ for exporting countries such as Russia. In an estimated DSGE model for Canada Dib (2008) finds that commodity price shocks significantly contribute to real business cycle dynamics. In that context, flexible exchange rates can offset some of the negative effects from external shocks. Sosunov and Zamulin (2007) and Semko (2013) employ DSGE models calibrated as well as estimated for the Russian economy to conclude that a monetary policy reaction to oil price shocks is redundant if oil revenues can be saved in some stabilization fund. Sosunov and Zamulin (2007) and also Konorev (2011) find consumer price inflation (CPI) targeting to be the optimal monetary policy in the case of Russia. Herz et al. (2015) calibrate the model by Ratto et al. (2009) to the Russian economy to conclude that CPI targeting is superior to the alternative of targeting the ruble price of oil, a strategy following the idea proposed by Frankel (2005) to target the price of the most important export commodity expressed in local currency.

The most recent and detailed work on the Russian economy within a DSGE framework is the one by Malakhovskaya and Minabutdinov (2014). They find evidence for commodity export shocks affecting domestic production in the short-run as well as long-term. However, although they authors account for many important features of the Russian economy, they assume a completely floating exchange rate and by that ignore the implications that exchange rate management might has on the transmission of shocks. To address this deficiency, the framework of this study is designed to explicitly account for the exchange rate policy of the Bank of Russia (CBR) that has been described as a strategy to smooth the behavior of the ruble's exchange rate against the US dollar and later a dual-currency basket consisting of the dollar and the euro.

Whereas the inclusion of the nominal exchange rate in the policy rate reaction function is a common feature of small open economy (SOE) models, little work has been done so far to take into account direct central bank interventions on the foreign exchange market that are characteristic for most of the economies targeting their nominal exchange rate behavior. Benes et al. (2015) built on a financial system following Edwards and Vegh (1997) and construct a model in which sterilized central bank interventions stabilize the exchange rate but also change the portfolio composition of domestic commercial banks that entail further macroeconomic consequences via changes in the domestic credit rates. Herrera et al. (2013) extend their framework by considering an oil-exporting sector and calibrate the model parameters to the Colombian economy to argue that foreign exchange intervention increases the volatility of credit supply and consumption compared to the alternative policy strategy of inflation targeting via an interest rate rule. Another approach to account for foreign exchange interventions has been proposed by Montoro and Ortiz (2013) who built on Bacchetta and Van Wincoop (2006) to incorporate market microstructure of exchange rate determination into a SOE model. In particular they assume, that the foreign exchange market is operated by risk-averse dealers that process sale and purchase orders for foreign securities in exchange for domestic bonds from foreign investors and the domestic central bank. Interventions of the latter will cause the ratio of domestic to foreign assets held by the dealers and their demanded risk premium to change causing immediate movements in the nominal exchange rate. Based on their calibrated model, they argue that intervention can shelter the domestic economy from external shocks, in particular if they are rule-based. Malovana (2015) estimates a similar model for the Czech Republic. However, she excludes rule-based interventions from the estimated model specifications and analyzes their implication for the transmission of shocks in calibrated simulations only.

We build on the idea proposed by Montoro and Ortiz (2013) and further expand their model by an oil-exporting sector as well as productive capital. The resulting framework exhibits all necessary features of the Russian economy in general and the monetary policy in particular and enables the analysis of the effects that shocks to the oil price and capital flows, two key external disturbances, have on domestic variables in the presence of different monetary policy strategies. To the best of my knowledge, this is the first work that estimates a SOE model with an foreign exchange intervention mechanism built in.

The remainder of the chapter is structured as follows: Section 3.2 presents the derivation of the model equations. Details on the estimation are outlined in Chapter 3.3. Estimation results and an analysis of the vulnerability of the domestic economy based on the estimated parameters and shocks are presented in 3.4, whereas Section 3.5 analyzes alternative policy strategies to cope with external shocks based on the estimated model parameters and the policy strategy in place. Section 3.6 concludes.

3.2 Model

The model used for estimation and simulation in the following sections is built on the standard small open economy (SOE) model in the spirit of Galí and Monacelli (2005), Monacelli (2005) and Justiniano and Preston (2010), featuring several kinds of rigidities like Calvo (1983)-pricing, partial indexation, habit formation and deviations from the law of one price for internationally-traded goods. However, it is extended in several ways to exhibit important characteristics of the Russian economy. In particular, we include an oil sector whose export revenues generate income for the domestic households. For an appropriate representation of the monetary policy, we follow Montoro and Ortiz (2013) in incorporating a foreign exchange market on which the central bank can influence its currency's exchange rate via sales and purchases of foreign securities. Finally, contrary to standard SOE models that abstract from investment, we allow for the formation of productive formation to gauge the effects that monetary policy has on its dynamics via the interest rate channel. The remainder of this section derives the model equations from the optimal behavior of the different agents and sectors in the economy and the consequential equilibrium conditions for particular markets and dynamics of individual variables. The full set of log-linearized model equations used for estimation and simulation can be found in Appendix B.

3.2.1 Households

The domestic economy is populated by a continuum of symmetric households. Households obtain utility from the consumption of goods and disutility from hours worked. The expected present value of utility for a representative household is given by:

$$E_0\left[\sum_{t=0}^{\infty}\beta^t\varepsilon_t^b U\left(\frac{(C_t-H_t)^{1-\sigma}}{1-\sigma}-\frac{\varepsilon_t^l L_t^{1+\phi}}{1+\phi}\right)\right] \tag{3.1}$$

where C_t is total consumption, $H_t = hC_{t-1}, 0 \leq h \leq 1$ is external habit formation and L_t is the labor effort. The parameters σ and ϕ capture the intertemporal elasticity of substitution and the inverse Frisch labor supply elasticity, respectively. ε^b is a shock to the discount factor β whereas ε^l represents a labor supply shock. Households earn the nominal wage W_t on their supplied labor services, receive interest income from holding domestic bonds B_t, and rental income from the supply of capital goods K_t to domestic producers. In addition, households receive profits Π_t from firms, commodity exports, and foreign exchange dealers. Income is spent on consumption and investment goods at the price level P_t. The household's budget constraint is thus given by:

$$\begin{aligned} &P_t\left(C_t+I_t\right)+B_t+\tfrac{\psi}{2}\left(B_t-\bar{B}\right)^2+\Psi\left(u_t\right)K_{t-1}= \\ &\left(1+\tilde{r}_{t-1}\right)B_{t-1}+W_tL_t+\tilde{r}_{k,t}u_tK_{t-1}+\Pi_t, \end{aligned} \tag{3.2}$$

where $\frac{\psi}{2}\left(B_t-\bar{B}\right)^2$ describe portfolio adjustment costs in the sense of Schmitt-Grohe and Uribe (2003), while u_t denotes the utilization rate of installed capital and $\Psi\left(\cdot\right)$ the costs associated with its adjustment. According to Christiano et al. (2005), they are zero in steady state. In each period, households maximize the present value of their expected lifetime utility by choosing the optimal levels of consumption, investment, hours worked, capital rented out, its utilization rate, and domestic bond holdings subject to their budget constraint and the capital accumulation function which is given by:

$$K_t=\left(1-\delta\right)K_{t-1}+F_t\left(I_t,I_{t-1}\right), \tag{3.3}$$

where $0 \leq \delta \leq 1$ is the depreciation rate and $F_t\left(I_t,I_{t-1}\right)=\left[1-S\left(\frac{\varepsilon_t^i I_t}{I_{t-1}}\right)\right]I_t$ is the cost of investment adjustments with ε_t^i being an investment specific disturbance evolving according to an AR(1) process, with an i.i.d. error term η_t^i with zero mean and variance $\sigma^2_{\eta^i}$. Following Christiano et al. (2005), the function $S(\cdot)$ and its first derivative equal zero, so that the adjustment costs only depend on the second-order derivative with $S''(\cdot) = \varkappa > 0$.

The resulting first order conditions are as follows:

$$\varepsilon_t^b (C_t - H_t)^{-\sigma} = \lambda_t \tag{3.4}$$

$$\varepsilon_t^l L_t^{\varphi} \varepsilon_{b,t} = \lambda_t w_t \tag{3.5}$$

$$\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\tilde{r}_{k,t+1} + T_{t+1}(1-\delta)\right) = T_t \tag{3.6}$$

$$\lambda_t T_t F_t^{'} (I_t, I_{t-1}) + \lambda_{t+1} T_{t+1} F_{t+1}^{'} (I_{t+1}, I_t) = \lambda_t \tag{3.7}$$

$$\beta \lambda_{t+1} \frac{1+\tilde{r}_t}{1+\Psi\left(B_t - \bar{B}\right)} \frac{1}{\pi_{t+1}} = \lambda_t \tag{3.8}$$

$$\tilde{r}_{k,t} = \Psi' (u_t), \tag{3.9}$$

$$\tag{3.10}$$

where T_t is the shadow price of capital.

Consumption and savings Combining the first order conditions with respect to consumption and the holding of bonds, results in the following optimal intertemporal consumption-savings decision:

$$\frac{\varepsilon_t^b (C_t - H_t)^{-\sigma}}{\varepsilon_{t+1}^b (C_{t+1} - H_{t+1})^{-\sigma}} = \beta \frac{1+\tilde{r}_t}{1+\Psi\left(B_t - \bar{B}\right)} \frac{1}{\pi_{t+1}}. \tag{3.11}$$

Total consumption is a composite index defined by:

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} (C_{H,t})^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} (C_{F,t})^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{3.12}$$

where $C_{H,t}$ and $C_{F,t}$ denote indexes of tradeable consumption goods produced domestically and abroad given by:

$$C_{H,t} = \left(\int_0^1 C_{H,t}^{\frac{\epsilon-1}{\epsilon}} (i)\, \mathrm{d}i\right)^{\frac{\epsilon}{\epsilon-1}} \text{ and } C_{F,t} = \left(\int_0^1 C_{F,t}^{\frac{\epsilon-1}{\epsilon}} (i)\, \mathrm{d}i\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{3.13}$$

where α is the share of foreign goods in the domestic consumption basket, $\eta > 0$ is the elasticity of substitution between domestic and foreign goods, and $\epsilon > 1$ is the elasticity of substitution between varieties of goods indexed by $i \in [0, 1]$.

The optimal allocation of consumption expenditures within each category of goods is given by:

$$C_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\theta} C_{H,t} \text{ and } C_{F,t}(i) = \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\theta} C_{F,t}, \tag{3.14}$$

with $P_{H,t}$ and $P_{F,t}$ being the price indexes for the domestic and foreign consumption bundles. Finally, consumption across domestic and foreign goods (imports) is optimally allocated according to:

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \text{ and } C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t, \tag{3.15}$$

with P_t being the total consumer price index:

$$P_t = \left[(1-\alpha)(P_{H,t})^{1-\eta} + \alpha(P_{F,t})^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{3.16}$$

Investment and capital accumulation Households own the total capital stock of the economy that they rent out to domestic producers at the rental rate $\tilde{r}_{k,t}$. They can alter the effective capital stock used for production either by investment in new capital I_t or by adjusting its rate of utilization u_t. From the first order condition with respect to the capital stock the following expression for the shadow price of capital is obtained:

$$T_t = E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\left(T_{t+1}(1-\delta)\right) + \tilde{r}_{k,t+1}u_{t+1} - \Psi(u_{t+1})\right]. \tag{3.17}$$

Thus, the shadow price of capital depends positively on its expected value and expected real returns, adjusted for depreciation and the degree of utilization, and negatively on the expected real return on bonds.

New capital is invested according to:

$$\begin{aligned} &T_t S'\left(\frac{\varepsilon_t^i I_t}{I_{t-1}}\right)\frac{\varepsilon_t^i I_t}{I_{t-1}} - \beta E_t T_{t+1}\frac{\lambda_{t+1}}{\lambda_t}S'\left(\frac{\varepsilon_{t+1}^i I_{t+1}}{I_t}\right)\left(\frac{\varepsilon_{t+1}^i I_{t+1}}{I_t}\right)\frac{\varepsilon_{t+1}^i I_{t+1}}{I_t} + 1 \\ &= T_t\left(1 - S\left(\frac{\varepsilon_{t+1}^i I_{t+1}}{I_t}\right)\right). \end{aligned} \tag{3.18}$$

Analogously to private consumption, total investment expenditures are an aggregate of domestic and foreign investment goods:

$$I_t = \left[(1-\alpha)^{\frac{1}{\eta}}(I_{H,t})^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}}(I_{F,t})^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{3.19}$$

so that total investment spending is optimally allocated to domestic and foreign goods according to:

$$I_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} I_t \text{ and } I_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} I_t. \tag{3.20}$$

For simplicity, we assume that the share of foreign goods, the elasticities of substitution between different types of goods and different origins of goods are the same for consumption and investment. Furthermore, final goods can be used for both purposes, so that all relevant price indexes relate to both spending aggregates.

Wage setting and labor supply Following Erceg et al. (2000), we assume that each monopolistically competitive household $h \in [0,1]$ supplies a differentiated labor service $L_t(h)$ to the production sector. Individual labor services are bundled by an employment agency into the labor index L_t according to the following Dixit-Stiglitz aggregation function:

$$L_t = \left[\int_0^1 L_t(h)^{\frac{1}{(1+\lambda^w)}} \, \mathrm{d}h \right]^{(1+\lambda^w)}, \tag{3.21}$$

where $\lambda^w > 0$ is the net wage markup. Given the individual wages $W_t(h)$ set by each of the households, the employment agency minimizes the cost for the production of a given amount of the labor index which is sold to the production sector at the aggregate wage index W_t:

$$W_t = \left[\int_0^1 W_t(h)^{-\frac{1}{\lambda^w}} \, \mathrm{d}h \right]^{-\lambda^w}. \tag{3.22}$$

Households set their nominal wages to maximize intertemporal utility subject to the demand for their labor services given by:

$$L_t(h) = \left[\frac{W_t(h)}{W_t} \right]^{-(1+\lambda^w)/\lambda^w} L_t. \tag{3.23}$$

Each period only a random fraction $1 - \theta^w$ of households can adjust its wage. A household that is able to adjust will set a new optimal nominal wage, $\tilde{W}_t(h)$, taking into account the expected time until the next possible adjustment. Households that are not able to optimally reset their wage adjust their current wage to past inflation:

$$W_t(h) = \left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma^w} W_{t-1}(h), \tag{3.24}$$

where $0 \leq \gamma^w \leq 1$ is the degree of wage indexation. It follows for the dynamic representation of the wage index:

$$W_t = \left[(1-\theta^w) \left(\tilde{W}_t \right)^{-\frac{1}{\lambda^w}} + \theta^w \left(\left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma^w} W_{t-1} \right)^{-\frac{1}{\lambda^w}} \right]^{-\lambda^w}. \tag{3.25}$$

3.2.2 Production and retail sectors

Intermediate goods producers There exists a continuum of monopolistically competitive intermediate goods producers indexed by $j \in [0, 1]$. Each firm j uses physical capital K_{t-1} and labor services provided by households L_t as inputs to produce intermediate goods Y according to the following Cobb-Douglas production function:

$$Y_t(j) = A_t \left(u_t(j) K_{t-1}(j)\right)^{\psi} L_t(j)^{1-\psi} - \Phi, \tag{3.26}$$

where A_t denotes a total factor productivity shock, with $\ln A_t = \rho_a \ln A_{t-1} + \eta_t^a$ and η_t^a representing and i.i.d. normal shock with zero mean and variance $\sigma^2_{\eta_t^a}$, u_t the utilization rate of physical capital and Φ fixed costs. Intermediate producers take factor prices as given and minimize their costs for a particular level of output. For the labor demand it follows that:

$$L_t = \frac{1-\psi}{\psi} \frac{\tilde{r}_{k,t} u_t K_{t-1}}{W_t}. \tag{3.27}$$

The ratio of capital and labor will be the same across all intermediate goods producers and equal to the average proportion. Marginal costs of production are then given by:

$$MC_t = A_t^{-1} \tilde{r}_{k,t}^{\psi} W_t^{1-\psi} \psi^{-\psi} (1-\psi)^{-(1-\psi)}. \tag{3.28}$$

We assume that producers of domestic goods are capable of discriminating prices between goods sold on the domestic market and exports X_t, so that the price of the latter, $P_{X,t}$, is set in foreign currency. Real marginal costs of goods produced for external demand are given by:

$$MC_{X,t} = \frac{P_t MC_t}{\tilde{e}_t P_{X,t}}, \tag{3.29}$$

where $\tilde{e}_t$ is the nominal exchange rate expressed in domestic currency per foreign currency units.

For nominal profits of firm j on domestic and foreign markets it then follows:

$$\Pi_{H,t}(j) = \left(P_{H,t}(j) - MC_t\right) \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-(1+\lambda^p)/\lambda^p} Y_t - MC_t \Phi, \tag{3.30}$$

$$\Pi_{X,t}(j) = \left(P_{X,t}(j) - MC_{X,t}\right) \left(\frac{P_{X,t}(j)}{P_{X,t}}\right)^{-(1+\lambda^p)/\lambda^p} X_t - MC_{X,t} \Phi. \tag{3.31}$$

Intermediate goods producers set prices for their products following Calvo (1983), so that in each period only a random fraction of $1-\theta$ firms can set prices optimally. Analogously to the wage-setting problem, the remaining prices are adjusted according to a simple indexation rule:

$$P_{H,t}(j) = \left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta^h} P_{H,t-1}(j), \tag{3.32}$$

$$P_{X,t}(j) = \left(\frac{P_{X,t-1}}{P_{X,t-2}}\right)^{\delta^x} P_{X,t-1}(j), \tag{3.33}$$

where $0 \leq \delta^h \leq 1$ and $0 \leq \delta^x \leq 1$ are the degrees of price indexation. Producers that are allowed to re-optimize their prices know the probability of being able to adjust in the future. Profit maximization, taken the aggregate price level and the total demand as given, results in the following first order conditions:

$$E_t \sum_{i=0}^{\infty} \left(\beta\theta^h\right)^i \lambda_{t+i} Y_{H,t+i}(j) \left(\frac{\tilde{P}_{H,t}(j)}{P_{H,t}} \left(\frac{\left(P_{H,t-1+i}/P_{H,t-1}\right)^{\delta^h}}{P_{H,t+i}/P_{H,t}}\right) - (\lambda^p)\, MC_{t+i}\right) = 0 \tag{3.34}$$

and

$$E_t \sum_{i=0}^{\infty} \left(\beta\theta^x\right)^i \lambda_{t+i} X_{t+i}(j) \left(\frac{\tilde{P}_{X,t}(j)}{P_{X,t}} \left(\frac{\left(P_{X,t-1+i}/P_{X,t-1}\right)^{\delta^x}}{P_{X,t+i}/P_{X,t}}\right) - (\lambda^p)\, MC_{X,t+i}\right) = 0. \tag{3.35}$$

Domestic retailers Perfectly competitive domestic retailers bundle intermediate goods to transform them into final goods they sell on the domestic market according to the following technology:

$$Y_{H,t} = \left[\int_0^1 Y_{H,t}(j)^{\frac{1}{(1+\lambda^p)}}\, \mathrm{d}j\right]^{(1+\lambda^p)}. \tag{3.36}$$

Given the prices of individual intermediate goods $P_{H,t}(j)$ set by each of the firms, the retailer minimizes the cost for the production of a given amount of the final good which is sold to the households at the aggregate price index $P_{H,t}$:

$$P_{H,t} = \left[\int_0^1 P_{H,t}(j)^{-\frac{1}{\lambda^p}}\, \mathrm{d}j\right]^{-\lambda^p}. \tag{3.37}$$

Given the optimal price setting behavior of the intermediate goods producers and the partial indexation in (3.34), it follows for the dynamics of the domestic goods price index:

$$P_{H,t} = \left[\left(1-\theta^h\right)\tilde{P}_{H,t}(j)^{-1/\lambda^p} + \theta^h \left(P_{H,t-1}\left(\frac{P_{H,t-1}}{P_{H,t-2}}\right)^{\delta^h}\right)^{-1/\lambda^p}\right]^{-\lambda^p}. \tag{3.38}$$

Exporters Analogously to domestic retailers, perfectly competitive exporting firms bundle intermediate goods produced for the foreign market and transform them into final goods according to the following technology:

$$X_t = \left[\int_0^1 X_t(j)^{\frac{1}{(1+\lambda^p)}} \mathrm{d}j \right]^{(1+\lambda^p)}, \tag{3.39}$$

Given the prices of individual intermediate goods $P_{X,t}(j)$ set by each of the firms, the exporter minimizes the cost for the production of a given amount of the exported good which is sold to the rest of the world at the aggregate price index $P_{X,t}$:

$$P_{X,t} = \left[\int_0^1 P_{X,t}(j)^{-\frac{1}{\lambda^p}} \mathrm{d}j \right]^{-\lambda^p}. \tag{3.40}$$

Given the optimal price setting behavior of the intermediate goods producers and the partial indexation in (3.35), it follows for the dynamics of the exported goods price index:

$$P_{X,t} = \left[(1-\theta^x) \tilde{P}_{X,t}(j)^{-1/\lambda^p} + \theta^x \left(P_{X,t-1} \left(\frac{P_{X,t-1}}{P_{X,t-2}} \right)^{\delta^x} \right)^{-1/\lambda^p} \right]^{-\lambda^p}. \tag{3.41}$$

Total demand for export goods in the rest of the world is, analogously to the demand for imported goods at home presented in Equation (3.15), given by

$$X_t = \alpha^* \left(\frac{P_{X,t}}{P_t^*} \right)^{-\eta^x} Y_t^*. \tag{3.42}$$

Importers We follow Justiniano and Preston (2010) in assuming that there exist monopolistically competitive retailers of imported goods for which the law of one price holds at the docks. Importers bundle foreign differentiated goods and sell them on the domestic market according to the following technology:

$$M_t = \left[\int_0^1 M_t(j)^{\frac{1}{(1+\lambda^p)}} \mathrm{d}j \right]^{(1+\lambda^p)}. \tag{3.43}$$

Analogously to retailers of domestic products and exporters, only a fraction of $1-\theta^m$ importers is capable of optimally adjusting prices, while the remaining retailers follow a simple indexation rule. Importers take the demand for foreign goods and its aggregate price level as given and maximize the expected value of future profits under consideration of the probability of price resets in the future. The optimal price set in the current period then results from the following first order condition:

$$E_t \sum_{i=0}^{\infty} (\beta\theta^m)^i \lambda_{t+i} M_{t+i}(j) \left(\frac{\tilde{P}_{M,t}(j)}{P_{M,t}} \left(\frac{(P_{M,t-1+i}/P_{M,t-1})^{\delta^m}}{P_{M,t+i}/P_{M,t}} \right) - (\lambda^p) MC_{M,t+i} \right) = 0, \quad (3.44)$$

with

$$MC_{M,t} = \frac{\tilde{e}_t P_t^*}{P_{M,t}} \quad (3.45)$$

being the real marginal cost for importers, the purchasing price in domestic currency units relative to the price level of imported goods. The law of motion for the price index of imported goods is then given by:

$$P_{M,t} = \left[(1-\theta^m) \tilde{P}_{M,t}(j)^{-1/\lambda^p} + \theta^m \left(P_{M,t-1} \left(\frac{P_{M,t-1}}{P_{M,t-2}} \right)^{\delta^m} \right)^{-1/\lambda^p} \right]^{-\lambda^p}. \quad (3.46)$$

3.2.3 Oil exporting sector

The economy is endowed with an infinite amount of oil that is exported at an exogenous world market price in foreign currency, $P_{o,t}$. In every period, revenues of the oil sector in local currency units are then given by:

$$Y_{o,t} = \tilde{e}_t P_{o,t} O_t, \quad (3.47)$$

where O_t is the exported volume, that is assumed to be constant. Any variation in the export revenues thus stems from movements in the world market price or the nominal exchange rate. The real foreign currency price is assumed to follow an AR(1) process in logs, with an i.i.d. shock term with zero mean and variance $\sigma^2_{\eta^{po}}$. All profits of the oil sector are transferred to the households.

3.2.4 Foreign exchange dealers

Following Montoro and Ortiz (2013), we extend the otherwise standard model by a continuum of risk-averse dealers d on the unit interval that operate the secondary bond market by executing orders they receive from households, foreign investors and the domestic central bank. Whereas households and foreign investors hold only domestic and foreign bonds, respectively, the central bank engages in both types of securities. It is assumed to exchange the domestic bonds it issues for foreign securities. Each of the dealers receives purchase or sale orders for domestic bonds from households and the central bank, $\omega_t(d)$ and $\omega_{CB,t}(d)$, as wells as purchase or sale orders for foreign bonds from foreign investors and the central bank, $\omega_t^*(d)$ and $\omega_{CB,t}^*(d)$. All dealers receive the same amounts of orders, that are exchanged among each other. At the end of every period, the holdings of domestic and foreign bonds of each dealer, $B_t(d)$ and $B_t^*(d)$, are given by:

$$B_t(d) + \tilde{e}_t B_t^*(d) = \omega_t(d) - \omega_{CB,t}(d) + \tilde{e}_t\left(\omega_t^*(d) + \omega_{CB,t}^*(d)\right). \tag{3.48}$$

All profits are transferred to the households.

Dealers are assumed to be risk-averse and short-sighted. They maximize their expected end-of-period utility which is given by the following constant absolute risk aversion function:

$$-E_t(d)\, e^{-\gamma\Omega_{t+1}(d)}, \tag{3.49}$$

where γ is the coefficient of absolute risk aversion and $\Omega_{t+1}(d)$ is total investment after returns of dealer d, given by:

$$\Omega_{t+1}(d) = (1+r_t)\, B_t(d) + (1+r_t^*)\, E_t(d)\, \tilde{e}_{t+1} B_t^*. \tag{3.50}$$

Substituting for the dealer's resource constraint and log-linearizing the excess return on foreign bonds, with $e_t = \ln \tilde{e}_t$, leads to:

$$\Omega_{t+1}(d) \approx (1+r_t)\left[\omega_t(d) - \omega_{CB,t}(d) + \tilde{e}_t\left(\omega_t^*(d) + \omega_{CB,t}^*(d)\right)\right] \tag{3.51}$$

$$+ \left(r_t^* - r_t + E_t(d)\, e_{t+1} - e_t\right) B_t^*(d). \tag{3.52}$$

Maximizisation of the utility function with respect to end-of-period foreign bond holdings results in the following first order condition:

$$-\gamma\left(r_t^* - r_t + E_t(d)\, e_{t+1} - e_t\right) + \gamma^2 B_t^*(d)\, \sigma_{\Delta e}^2, \tag{3.53}$$

with $\sigma_{\Delta e}^2$ being the unconditional variance of the rate of nominal exchange rate depreciation. This last term results from assumptions about the exchange rate in period $t+1$, the only non-predetermined variable in the optimization problem. From (3.53) it follows for the demand for foreign bonds of each dealer d:

$$B_t^*(d) = \frac{r_t^* - r_t + E_t(d)\, e_{t+1} - e_t}{\gamma\sigma_{\Delta e}^2}. \tag{3.54}$$

Thus, demand for foreign bonds is positively affected by an interest rate differential to domestic bonds, an expected appreciation of the foreign currency, lower risk aversion and lower exchange rate volatility.

3.2.5 Central bank

The monetary authority sets the short-term interest rate according to a Taylor (1993)-type monetary policy rule. In particular, it reacts to deviations of the consumer price inflation from its trend as well as excessive deviations of the nominal depreciation rate of the ruble. The lagged value of the policy rate is considered to account for its rather smooth development. We assume that (in log-linear representation):

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)\left(\phi_\pi \pi_t + \phi_{\Delta e} \Delta e_t\right) + \eta_t^r, \tag{3.55}$$

where ρ_i is the degree of interest rate smoothing, ϕ_π and $\phi_{\Delta e}$ are the reaction coefficients to movements of the inflation rate and the degree of exchange rate depreciation, and η_t^r is an i.i.d. normal error with zero mean and variance $\sigma^2_{\eta^r}$, capturing non-systematic interest setting behavior.

In addition to the interest rate as a standard monetary policy operating target, the central bank uses interventions on the foreign exchange market as an instrument to stabilize the behavior of the nominal exchange rate. The monetary authority finances the acquisition of foreign exchange reserve by the issuance of its own securities B_t. We assume that the central bank is capable to fully sterilize its interventions so that it is able to control the interest rate paid on its bonds, regardless of the volume of securities issued or bought. As outlined in the previous section, securities in the foreign exchange market are traded via risk-averse dealers which execute the orders they receive from households, foreign investors and the domestic central bank. In contrast to the capital flows generated by foreign investors, purchases and sales of international reserves by the central bank are assumed to be carried out systematically. In particular, a monetary authority intended to mitigate exchange rate fluctuations is expected to counter appreciation (depreciation) pressures on its currency resulting from the excess demand for (supply of) domestic assets and thus to purchase (sell) foreign bonds in exchange for domestic ones. Following the standard approach to model interest rate rules, the foreign bond sale orders from the central bank can be expressed (in log-linear representation) as:

$$\omega^*_{CB,t} = \phi_{\Delta e,int} \Delta e_t + \eta_t^{int}, \tag{3.56}$$

with $\phi_{\Delta e,int}$ being the reaction coefficient to movements of the degree of exchange rate depreciation, and η_t^{int} an i.i.d. normal error term with zero mean and variance $\sigma^2_{\eta^{int}}$, capturing non-systematic foreign exchange interventions. Different from the dynamic behavior of the policy rate, the volume of interventions does not exhibit persistence over time but rather strongly depends on current economic conditions the central bank is reacting to. Thus, it is reasonable to not consider a smoothing parameter in the intervention equation.

3.2.6 Foreign economy

Based on the small open economy assumption, the behavior of foreign economy variables is assumed to be exogenous to the development of domestic variables. We follow Justiniano and Preston (2010) in specifying the dynamics of the rest of the world output, inflation and interest rate as an VAR(2) in logs, such that:

$$\begin{bmatrix} y_t^* \\ \pi_t^* \\ r_t^* \end{bmatrix} = \begin{bmatrix} \rho_{11}^* & \rho_{12}^* & \dots & \rho_{16}^* \\ \rho_{21}^* & \rho_{22}^* & \dots & \rho_{26}^* \\ \rho_{31}^* & \rho_{32}^* & \dots & \rho_{36}^* \end{bmatrix} \begin{bmatrix} y_{t-1}^* \\ y_{t-2}^* \\ \pi_{t-1}^* \\ \dots \\ r_{t-2}^* \end{bmatrix} + \begin{bmatrix} \eta_t^{y^*} \\ \eta_t^{\pi^*} \\ \eta_t^{r^*} \end{bmatrix}, \tag{3.57}$$

where $\eta_t^{y^*}$, $\eta_t^{\pi^*}$ and $\eta_t^{r^*}$ are i.i.d. normal shocks with zero mean and standard deviations $\sigma_{\eta^{y^*}}$, $\sigma_{\eta^{\pi^*}}$ and $\sigma_{\eta^{r^*}}$.

3.2.7 Aggregation and market clearing

Goods and factor markets Domestic goods market clearing requires non-oil goods production, net of utilization adjustment costs, to be equal to the demand for consumption, investment, non-oil exports and imports $M_t = C_{F,t} + I_{F,t}$:

$$Y_t = C_t + I_t + X_t - M_t + G_t + \omega(u_t) K_{t-1}, \tag{3.58}$$

where G_t captures government spending that is assumed to be exogenous and follow an AR(1) process in logs, with an i.i.d normal error term with zero mean and variance $\sigma^2_{\eta^g}$. Total real GDP is then defined as the sum of non-oil GDP and oil revenues:

$$GDP_t = \frac{\tilde{e}_t P_{o,t} O_t + P_{H,t} Y_t}{P_{Y,t}}, \tag{3.59}$$

where $P_{Y,t}$ is the GDP deflator. The capital market clears when the capital supplied by domestic households equals the demand from domestic producers at the market rate for rented capital $\tilde{r}_{k,t}$. The market for labor is in equilibrium when the labor supplied by domestic households equals the labor demand from domestic producers at the aggregate wage.

Prices By definition, the GDP deflator equals the weighted average of the individual price levels of its components:

$$P_{Y,t} = (\phi_c + \phi_i) P_t + \phi_o (\tilde{e}_t P_{o,t}) + \phi_x \tilde{e}_t P_{X,t} - \phi_m P_{M,t}, \tag{3.60}$$

with ϕ_c, ϕ_i, ϕ_o, ϕ_x and ϕ_m being the shares of consumption, investment, oil revenues, non-oil exports and imports to GDP, respectively. The real exchange rate is defined as:

$$Q_t = \frac{\tilde{e}_t P_t^*}{P_t}. \tag{3.61}$$

Foreign exchange market Market clearing in the domestic market for foreign bonds requires the aggregate demand of foreign investors and the central bank to equal the end-of-period holdings of foreign bonds by all dealers:

$$\int_0^1 B_t^* (d) \, \mathrm{d}d = \int_0^1 \left(\omega_t^* (d) + \omega_{CB,t}^* (d)\right) \mathrm{d}d = \omega_t^* + \omega_{CB,t}^*. \tag{3.62}$$

Aggregating (3.54) over the continuum of dealers and substituting total demand by (3.62), the following modified uncovered interest rate parity (UIP) condition is obtained:

$$E_t e_{t+1} - e_t = r_t - r_t^* + \gamma \sigma_{\Delta e}^2 \left(\omega_t^* + \omega_{CB,t}^*\right). \tag{3.63}$$

The expression explicitly assumes that there is information homogeneity across all dealers so that the average expectation of the future nominal exchange rate is the same for all of them.

Risk aversion and short-sightedness of foreign exchange dealers results in an augmentation of the standard UIP condition by a time-variant risk premium that depends on foreign capital flows and central bank interventions. According to (3.63), the latter affect the nominal exchange rate through two mechanisms: the portfolio balance channel and the expectations channel. The former is defined by the last part of the UIP condition. Central bank interventions change the composition of domestic and foreign assets in the dealers' portfolios that have been chosen optimally based on their assessment of the respective returns and risks. A holding of a higher share of either security in their portfolio has thus to be compensated by a higher relative risk-adjusted return. Purchases (sales) of foreign bonds by the central bank increase (reduce) the relative share of foreign bonds in the dealers' portfolios. This will lead them to ask for a lower (higher) risk premium to be compensated for a relatively lower (higher) quantity of domestic currency they hold, resulting in a nominal appreciation (depreciation). The effect of central bank interventions on the exchange rate is the higher, the larger the risk premium factor $\gamma\sigma^2_{\Delta e}$, i.e. the more risk-averse dealers are or the higher the risk (uncertainty) in terms of the expected exchange rate volatility. The expectations channel is captured by the expected next period exchange rate. Rule-based interventions affect agents' beliefs about the future interventions and thus the dynamics of the exchange rate. All other variables kept equal, this will result in the exchange rate already today.

We assume that foreign capital flows are non-fundamental in the sense that they are not explained by any other model variable and evolve according to the following equation (in logs):

$$\omega^*_t = \rho_{\omega^*}\, \omega^*_{t-1} + \eta^{\omega^*}_t, \tag{3.64}$$

where $\eta^{\omega^*}_t$ is an i.i.d. normal shock with zero mean and variance $\sigma^2_{\eta^{\omega^*}}$.

Flow budget constraint The aggregation of the households budget constraint, the oil export revenues, profits of the foreign exchange dealers, firms and retail sectors as well as the equilibrium in the domestic bond market leads to the following flow budget constraint of the domestic economy:

$$B_t = (1 + \tilde{r}_{t-1})\, B_{t-1} + \tilde{e}_t P_{o,t} O_t + \tilde{e}_t P_{X,t} X_t - P_{M,t} M_t - \frac{\psi}{2}\left(B_t - \bar{B}\right)^2. \tag{3.65}$$

3.3 Estimation

We use the MATLAB preprocessor Dynare (see Adjemian et al., 2011) to solve and subsequently estimate the model using Bayesian techniques. Chris Sims' optimization routine CSMINWEL is used to obtain an initial estimate of the posterior mode, based on prior distributions and observable time series for endogenous model variables. To approximate the distribution of the parameters, we employ a random walk Metropolis–Hastings algorithm with two chains, each consisting of 500 000 parameter vector draws.

3.3.1 Data

For estimation 13 quarterly time series from the beginning of 2000 till the second quarter of 2015 are used. These include GDP, consumption, investment, the consumer price index, the producer price index as a proxy for prices of domestic goods, wages, the real exchange rate, the three-month interbank rate, capital flows, the oil price as well as series for foreign output, inflation and interest rates. Data for GDP, its aggregates and wages is taken from the Federal State Statistics Service (Rosstat). They are seasonally adjusted and transformed to real variables with the GDP deflator from the CBR. Finally, they are divided by the active labor force series from the OECD to obtain per capita values and detrended using the Hodrick-Prescott filter.

For the price variables, we seasonally adjust the indexes of domestic goods and consumer prices obtained from Rosstat and take the first log-differences to calculate the respective inflation rates. We take period averages of the 3-month MIBOR rate from the Bank of Russia and divide them by 400 to obtain the quarterly interest rate series. For the capital flows, data on private sector capital flows by the CBR is used and divided by nominal GDP in US dollars.

All foreign variables as well as the oil prices and the real exchange rate are expressed in terms of the dual-currency basket, that has been used as an exchange rate benchmark by the Bank of Russia since 2005. The weights of the US dollar and the euro have been adjusted five times. Since 2007 the basket weights of the dollar and the euro have been 0.55 and 0.45, respectively. We use this ratio for the whole sample under consideration. As has been argued by Malakhovskaya and Minabutdinov (2014), this simplification can be justified by the share of Russian exports to the euro area and Switzerland relative to the exports to its 15 main trade partners being around the same number. Foreign GDP, inflation and interest rate are thus weighted averages of the respective US and euro area time series, that are processed in the same way as the domestic variables described above. The real exchange rate is calculated by equating the changes in the nominal exchange rate index constructed from the bi-lateral ruble exchange rates against the dollar and the euro and the inflation differential between Russia and the weighted foreign average. Finally, the quarter-average spot price of Brent oil is converted to be expressed in terms of the currency basket and divided by the weighted average foreign consumer price index to obtain the respective real series.

Prior to estimation, all observable series are demeaned.

3.3.2 Priors and calibration

Most of the prior choices are motivated by Justiniano and Preston (2010). These include the ones for the consumption utility σ set to 1.20 with a standard deviation of 0.40, the inverse Frisch elasticity φ with mean 1.50 and standard deviation 0.75, and the habit parameter h centered around 0.50 with a standard deviation of 0.25. The priors for the elasticities of substitution between domestic and foreign goods are set for, both, the home country and the rest of the world to a mean of 1.50 and a standard deviation of 0.75. Priors for all Calvo parameters are set to a mean of 0.5 and a standard deviation of 0.10, whereas the priors for the degrees of indexation are set to the same mean but a standard deviation of 0.25. Choices for the priors for the fix cost parameter as well as the investment adjustment and capital utilization adjustment costs are set according to Smets and Wouters (2003). Priors for the central bank's reaction functions also follow common practice. The prior of the inflation reaction coefficient is set to 1.50 with a standard deviation of 0.30, whereas the priors for the exchange rate reaction parameters are centered around 0.50 with a standard deviation of 0.13 in both rules. The prior for the interest rate smoothing parameter is set to 0.80 and a standard deviation of 0.10. We fit an AR(1) process for the actual data on oil prices and capital flows to define the priors for the respective AR(1) parameters at a mean of 0.20 and 0.40 and standard deviations of 0.15, respectively. For all remaining AR(1) parameters, the respective priors are centered around 0.80 with a standard deviation of 0.10. For most of the standard deviations of model shocks, the prior means are chosen to be 0.01 with a standard deviation of 2. The choices for the shocks to capital flows, the oil price and central bank interventions are motivated by estimates of respective AR(1) processes. The complete set of prior choices is presented in Table 3.5.

The remaining parameters and steady-state values are calibrated, since they are either difficult to estimate or there exist strong evidence for a particular value in the data. Standard choices are made for the discount parameter ($\beta = 0.99$), implying a steady-state real interest rate of 4 percent, the share of capital in the production function ($\psi = 1/3$), the rate of depreciation of private capital ($\delta = 0.025$), i.e. an annual depreciation of 10 percent, and the net wage markup ($\lambda^w = 0.15$). The shares of consumption, investment, non-oil exports and imports to total output are calibrated to their average value over the sample period. In a similar way, the share of foreign goods in consumption and investment is fixed at 0.23. Matching the ratio of central bank reserves to GDP, the respective model equivalent, the ratio of domestic bonds to output is set to 0.9. Analogously, the proportion of oil exports to GDP is set to 0.17, the average of oil, oil products and gas. We choose this rather broad definition of commodity exports to properly account for the significance they have for the Russian economy. The close co-movements of crude oil and natural gas prices do not raise objections to treat the two commodities as one. As for the parameters of the UIP condition, the variance of the nominal exchange rate depreciation is calibrated to its sample period average of 0.0065, whereas the degree of risk aversion is set to 200. With the latter we deviate from the respective value in Bacchetta and Van Wincoop (2006) and Montoro and Ortiz (2013). Our choice is motivated by an estimate of the UIP equation using actual data on the exchange rate, the interest rate differential, private capital flows and central bank interventions. Following Justiniano and Preston (2010), we use estimates of a VAR(2) for the interaction of the three foreign variables in the model.

The complete set of calibrated parameters is presented in Table 3.4.

3.4 Results

3.4.1 Parameter estimates and model fit

The posterior means and probability intervals of the estimated parameters and the standard deviations of the model disturbances are presented in Table 3.6. All of them fall into a plausible range. Remarkably, prices for domestic and imported goods on the home market exhibit both, a higher frequency of prices changes (indicated by respectively lower Calvo parameters) and a higher degree of indexation when compared to exported goods, possibly as a result of a less stable price level development at home. Another remarkable difference is estimated for the elasticity of substitution between home and foreign goods from the domestic and the foreign perspective. In contrast to the demand for Russian goods abroad, demand for foreign goods in Russia is by less than a half influenced by relative price movements, pointing at a higher substitutability of Russian goods. Monetary policy is estimated to react modestly to variations in the inflation rate and the exchange rate, with the respective reaction coefficients being 1.44 and 0.50, while strongly smoothing the dynamics of the policy rate, with the AR(1) parameter estimated to be 0.93. The reaction coefficient for exchange rate movements in the intervention rule is estimated to be 0.90. Since there is no benchmark in the literature to assess the plausibility of this value, we compare the smoothed series for central bank interventions that has been employed in the estimation process to actual data that is available from the CBR from mid-2008. Figure 3.1 plots the smoothed series for central bank interventions against the actual interventions, demeaned over the respective sample, in relation to nominal GDP. The correlation of both series is 0.86 and the smoothed series in particular tracks the spikes of the actual data very well. We consider this finding as an important performance benchmark of the model used to characterize the Russian monetary policy and thus regard the setup capable of analyzing the actual and alternative policy strategies.

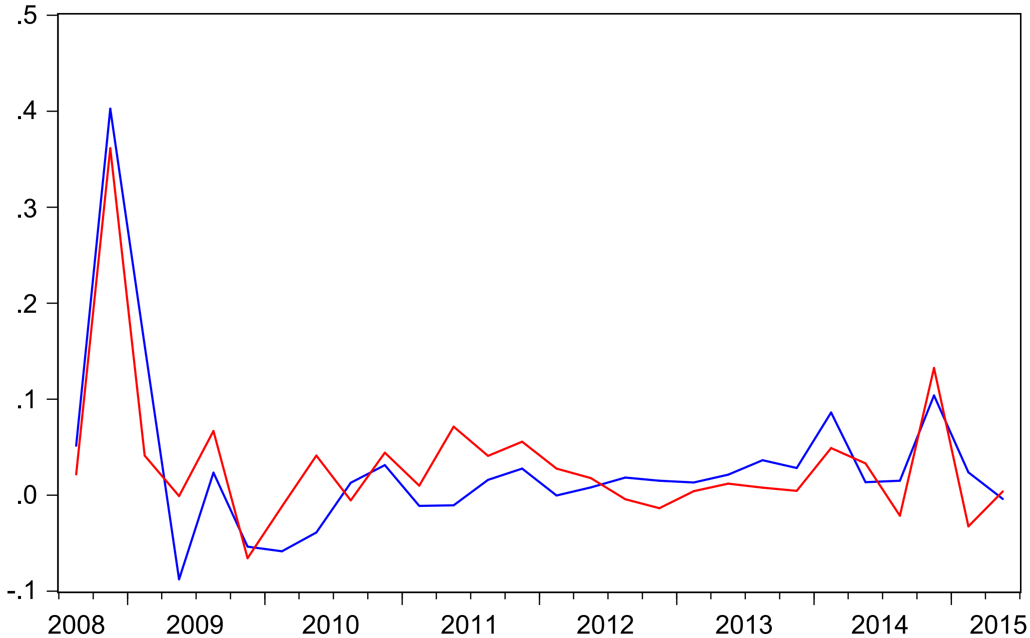

Figure 3.1: Smoothed central bank interventions (red) and actual demeaned interventions (blue) in relation to nominal GDP

3.4.2 Historical decomposition

Figures 3.2, 3.3 and 3.5 show the historical decompositions of the real exchange rate, real GDP and the consumer price inflation rate. From 2005 on, oil prices have put an appreciation pressure on the real ruble rate. In periods of high or rising oil prices, the central bank actively counters these dynamics by direct interventions or, to a lesser extent, policy rate rises. In crises times, there are mainly shocks to foreign capital flows affecting the value of the ruble. From the third quarter of 2008 well through 2009 and also, but to a lesser extent, at the turn of the years 2014 and 2015, capital outflows curbed the ruble's exchange rate. Whereas during the global financial crisis the CBR could soften the depreciation pressure via direct interventions and policy rate increases, the most recent Russian crisis episode is characterized

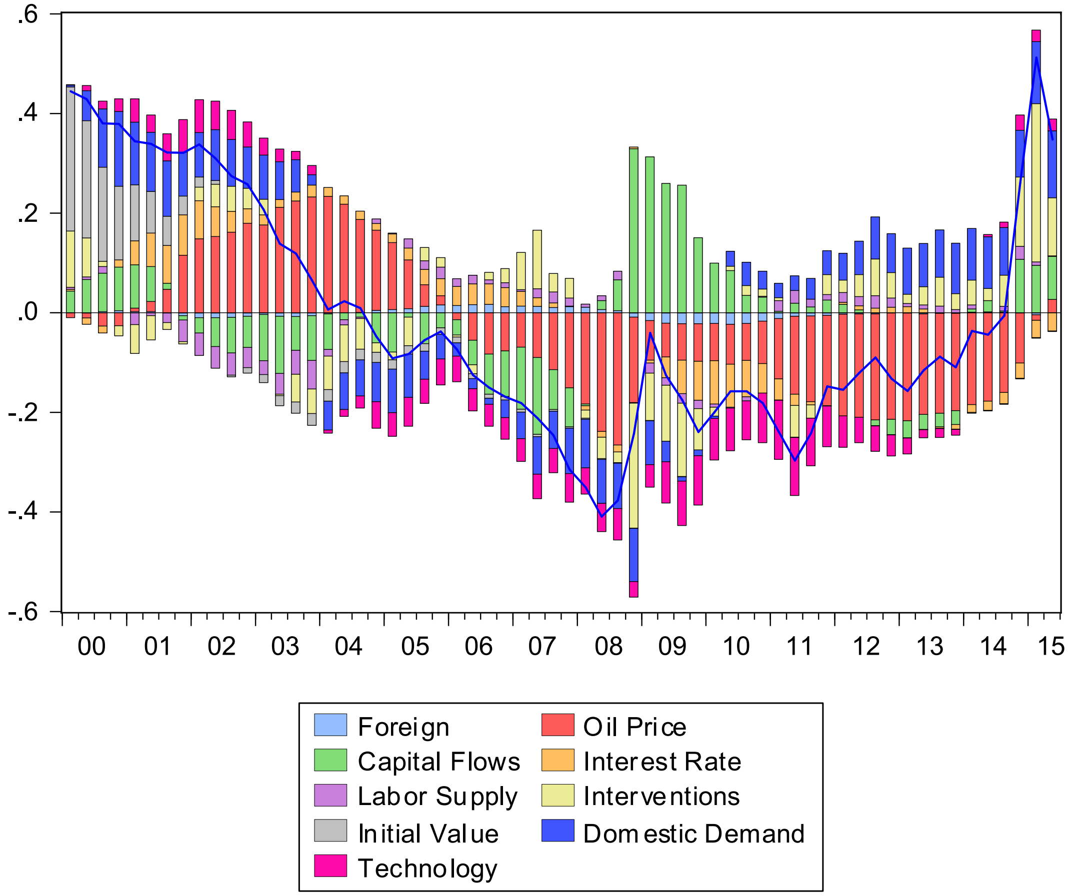

Figure 3.2: Historical decomposition of the real exchange rate (solid line)

by a non-sufficient policy response to keep the currency's value stable. This finding does not come as a surprise. After all, the ruble's depreciation at the end of 2014 has been much stronger than at the start of 2009. In addition, the CBR announced to let its currency freely float during the latest episode of depreciation. At least concerning its direct interventions, there is evidence in the historical decomposition for the monetary authority to have complied with its announcement.

Fluctuations in total real GDP are primarily caused by shocks to technology and domestic demand. Negative shocks to the latter, in particular investment, have been the main driver of the most recent downturn that has started to unfold already in mid-2013, whereas they have been stimulating the economy prior to that by the same token. The oil price has positively affected total Russian output in all quarters from spring 2007 on. This holds true

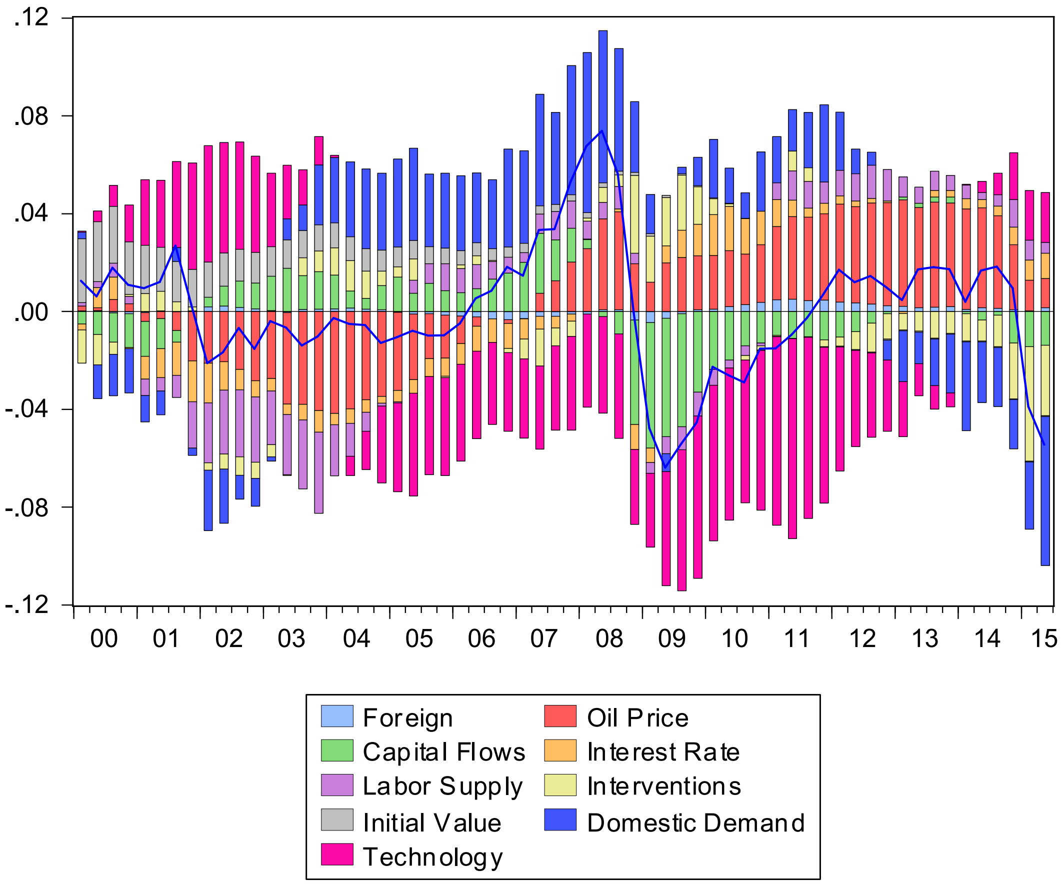

Figure 3.3: Historical decomposition of real GDP (solid line)

even for the drop in prices during the global financial crisis and in particular the most recent, from June 2014 onwards. This finding can be explained by the concurrent depreciation of the ruble's exchange rate during both episodes, limiting the decline in the commodity price expressed in domestic currency.

As concerns inflation, there does not appear to be a particular pattern of shocks influencing its rate in normal times, primarily owed to a relatively stable exchange rate. When large capital outflows put depreciation pressure on the ruble, however, the extent to which the central bank is able to offset their impact is crucial for the dynamics of the price level. During the global financial crisis, the CBR could keep the ruble relatively stable and lower the inflation rate in an environment of low economic activity. At the end of 2014, on the contrary, the insufficient and later scrapped strategy of preventing a depreciation dramatically increased the prices of imported goods and consequently also total inflation.

3.4.3 Forecast error variance decomposition

The forecast error variance decompositions for selected time horizons and variables based on the estimates of the model are presented in Table 3.1.[1] Around one half of the variations of domestic GDP can be explained by domestic demand shocks. More than one-third, in particular in the long-run, go back to investment shocks and their effect on deviations of the productive capital stock from its steady state. This finding corresponds to the historical decomposition of output according to which private investment shocks, seen individually, contributed most to GDP fluctuations in the past. Domestic supply shocks, mainly to technology, account for another quarter of domestic output variations. Capital flows and central bank interventions strongly affect GDP in the very short term, but rather weakly from two years onwards. Finally, oil price shocks account for roughly one-tenth of output fluctuations in the short-run as well as the long-term.

Fluctuations of the rate of consumer price inflation are primarily driven by monetary shocks, non-fundamental capital flows and domestic demand shocks, with their respective relative importance being almost constant over time. Prices for domestically produced goods are stronger affected by preference shocks and oil price disturbances, with the latter having a strong impact on households' incomes, consumption and hence their wage setting, affecting domestic producers' costs and consequently prices. Dynamics of prices for imported goods are to larger extent driven by shocks to capital flows and non-systematic interventions, since they, both, directly influence the behavior of the nominal exchange rate. Non-oil exports and imports are strongly affected by fluctuations of the oil price, with the impact of the latter influencing the real exchange rate strongest in the long-run, creating a channel to weigh on trade via relative price variances.

Based on the findings that nearly all domestic variables are substantially influenced by shocks to oil prices and capital flows at all horizons, the following section focuses on the effects that the two disturbances have on the Russian economy, given the estimated monetary policy in place. Starting with an isolated consideration of either shock, a situation is analyzed in which both disturbances hit the economy simultaneously. While the narrative considers the effects of positive shocks, the derived conclusions hold true in absolute terms also for the respective negative disturbances.

[1] Unless otherwise noted, all simulation results and reported variances in this work are based on simulations with the model parameters and standard deviations of shocks being calibrated to their respective estimated values.

1 Quarter	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	1.6	17.1	11.4	9.9	8.2	4.7	32.0	9.6	5.5	0.1
Consumption	2.8	2.4	2.0	26.2	11.4	35.8	0.5	2.0	16.8	0.0
Investment	0.0	0.4	0.6	2.7	2.3	20.4	0.0	72.2	1.4	0.0
Exports	0.2	15.2	15.3	5.6	33.6	19.1	0.1	1.5	3.7	5.6
Imports	3.4	11.9	9.9	5.0	35.6	23.7	0.1	8.2	2.3	0.0
Real wages	6.2	0.0	0.1	16.5	20.4	42.7	0.2	2.2	11.7	0.1
Inflation	10.6	20.0	20.1	4.7	15.6	23.5	0.1	0.5	4.4	0.5
Dom. prices	10.6	9.5	10.3	6.7	22.8	32.8	0.2	0.7	6.1	0.4
Real ER	0.2	45.3	30.6	2.3	8.6	10.6	0.1	0.3	2.0	0.1
4 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	0.7	7.0	7.6	19.8	7.4	4.5	13.4	30.4	8.9	0.3
Consumption	1.2	5.8	7.6	29.8	13.8	21.4	0.5	3.6	16.2	0.2
Investment	0.4	0.2	0.4	3.2	3.8	22.1	0.0	68.5	1.3	0.1
Exports	3.2	6.5	9.2	6.4	50.8	15.0	0.1	2.8	3.1	2.9
Imports	2.5	11.3	14.8	6.2	41.7	4.9	0.1	15.8	2.5	0.4
Real wages	3.3	3.0	4.1	29.6	22.4	25.6	0.3	3.7	8.0	0.1
Inflation	10.2	20.5	22.2	4.2	14.5	23.0	0.1	0.4	4.2	0.7
Dom. prices	9.8	10.3	11.5	6.0	22.3	32.7	0.2	0.7	6.0	0.5
Real ER	1.2	25.7	24.4	3.8	26.7	14.3	0.1	1.0	2.7	0.2
8 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	1.4	3.6	3.9	20.5	8.0	10.4	7.3	38.0	6.5	0.3
Consumption	3.6	4.3	5.5	29.0	22.8	17.4	0.4	4.6	12.2	0.3
Investment	1.2	0.2	0.2	3.8	6.5	23.0	0.0	63.8	1.1	0.1
Exports	8.4	3.3	4.3	6.9	58.9	9.4	0.1	5.0	2.2	1.6
Imports	7.6	6.1	7.8	5.4	50.3	4.3	0.0	16.3	1.6	0.6
Real wages	4.9	2.6	3.4	29.8	28.8	19.5	0.3	4.1	6.4	0.2
Inflation	10.3	20.2	21.8	4.1	14.7	23.3	0.1	0.4	4.2	0.9
Dom. prices	9.7	10.1	11.4	5.9	22.3	33.1	0.2	0.7	6.0	0.6
Real ER	5.0	18.4	17.6	4.7	38.0	11.2	0.1	2.4	2.3	0.3
∞	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	2.6	3.5	4.0	21.3	9.7	14.3	4.5	35.2	4.5	0.3
Consumption	6.0	5.4	6.8	23.2	24.9	16.0	0.2	9.8	7.2	0.4
Investment	2.8	1.6	2.1	4.7	10.5	22.8	0.0	54.3	0.9	0.3
Exports	10.3	7.4	9.4	7.1	47.2	5.0	0.0	10.7	1.2	1.6
Imports	10.6	9.0	11.4	4.4	45.8	6.2	0.0	10.7	1.0	1.0
Real wages	6.3	4.1	5.2	24.5	27.8	17.9	0.2	9.7	4.0	0.3
Inflation	10.5	20.1	21.9	4.1	15.0	22.8	0.1	0.5	4.2	0.9
Dom. prices	10.0	10.2	11.6	5.8	22.9	32.1	0.2	0.7	5.8	0.7
Real ER	7.1	17.0	17.5	5.2	36.3	8.0	0.1	6.4	1.7	0.7

Table 3.1: Forecast error variance decomposition at different horizons

3.4.4 Effects of oil price shocks

Following a positive oil price shock (Figure 3.6), household incomes rise on impact, leading to higher consumption expenditures. As a consequence, the marginal rate of substitution between consumption and labor increases, resulting in higher wages and consequently rising marginal costs and higher prices for domestically produced goods and total consumer prices. The consequent decline in real interest rates further stimulates household spending. These effects are very short-term, however. With their positive impact on the balance of payments, higher oil prices lead to a nominal and real exchange rate appreciation that is only in part offset by central bank interventions. The resulting relatively lower prices for foreign goods lead to an increase in imports and a decline in total consumer prices. On the other hand, foreign demand for domestically produced goods decreases sharply and persistently in the wake of the local currency's appreciation. The decline is, however, overcompensated by the increase in domestic demand due to higher incomes from oil exports, despite the fact that their rise is weaker when expressed in local currency units. Consequently, non-oil GDP is affected positively by the higher commodity prices, in particular also due to an increased capital stock as a result of risen investment spending.

In absolute terms, oil price shocks have the largest long-run effects on the real exchange rate, investment, non-oil exports, and imports. These findings largely correspond to the ones in Malakhovskaya and Minabutdinov (2014).

3.4.5 Effects of capital flow shocks

A capital inflow shock (Figure 3.7) increases the relative share of dealers' assets denominated in domestic currency, leading to an immediate appreciation of the latter. Its magnitude is weakened by the central bank's cutting of the domestic interest rate as well as direct interventions on the foreign exchange market. With constant world market prices, the nominal appreciation reduces the oil export revenues expressed in local currency units. Import prices decrease sharply in light of a stronger domestic currency. Due to lower interest rates and consequently lower capital costs, prices for domestically produced goods also drop, leading to a decline in total consumer prices. Consumption and investment spending is increased as a consequence of the unexpectedly risen ex-post real interest rate on savings. Nevertheless, in consequence of the sharp increase in its nominal value, the domestic currency also appreciates in real terms. Foreign demand for domestic non-oil goods drops, whereas imports increase as a result. The gradual reduction of capital inflows in combination with lower domestic interest rates cause the exchange rate to depreciate again after two quarters. In consequence of the low persistence of capital flow shocks, their direct effects dissolve already after one year. The expansive monetary policy in reaction to the initial currency appreciation, however, remains in place. This leads to reverse dynamics of the nominal exchange, overshooting its steady state level. With the inflation rate only slightly above its trend, this results in a real depreciation of the domestic currency, with the real exchange rate persistently exceeding its steady state level from the sixth quarter onwards. Dynamics of the GDP aggregates reverse in the light of this turnaround of relative prices. Exports of non-oil goods increase, whereas imports drop sharply. Domestic demand that has been initially stimulated by the capital inflows decreases in light of gradually increasing real interest rates. The reaction of total GDP follows a similar pattern.

In absolute terms, capital flow shocks have the largest long-run effects on the real exchange rate, the rate of nominal exchange rate appreciation, the domestic currency price of oil as well as investment, non-oil exports, and imports. The reaction of the central bank is not sufficient to counter the shock and to prevent it from having an impact on the domestic economy. On the contrary, due to their persistence, its measures affect real variables long after capital flows have returned to their steady state. For all real variables the unconditional variance is remarkably higher compared to the conditional variance up to the sixth quarter, when the shock dissolves completely.

3.4.6 Effects of simultaneous oil price and capital flow shocks

In addition to the analysis of the effects of oil price and capital flow shocks hitting the economy independently from each other, we also examine the case in which both disturbances occur simultaneously. The rationale is twofold: on the one hand, it appears to be reasonable that flows of foreign capital into or out of an oil-dependent economy are closely linked to the revenue prospects of the commodity sector. Whereas oil exporting firms profit directly from higher oil prices, the rest of the economy benefits from higher incomes and other second round effects. Public finances, on their part, are strongly influenced by revenues from commodity exports so that oil price dynamics have a notable impact on the attractiveness of sovereign bonds. On the other hand, a scenario of large capital outflows and falling oil prices features two main shocks the Russian economy has been confronted with during the year 2014. To analyze the effects that these two disturbances have on the domestic economy given the monetary policy strategy in place, the oil price is again shocked with the estimated intensity. In addition, the correlation of the capital flow shock to the oil price disturbance is calibrated to 0.4789, the correlation of the two respective smoothed shocks' series in the estimation.

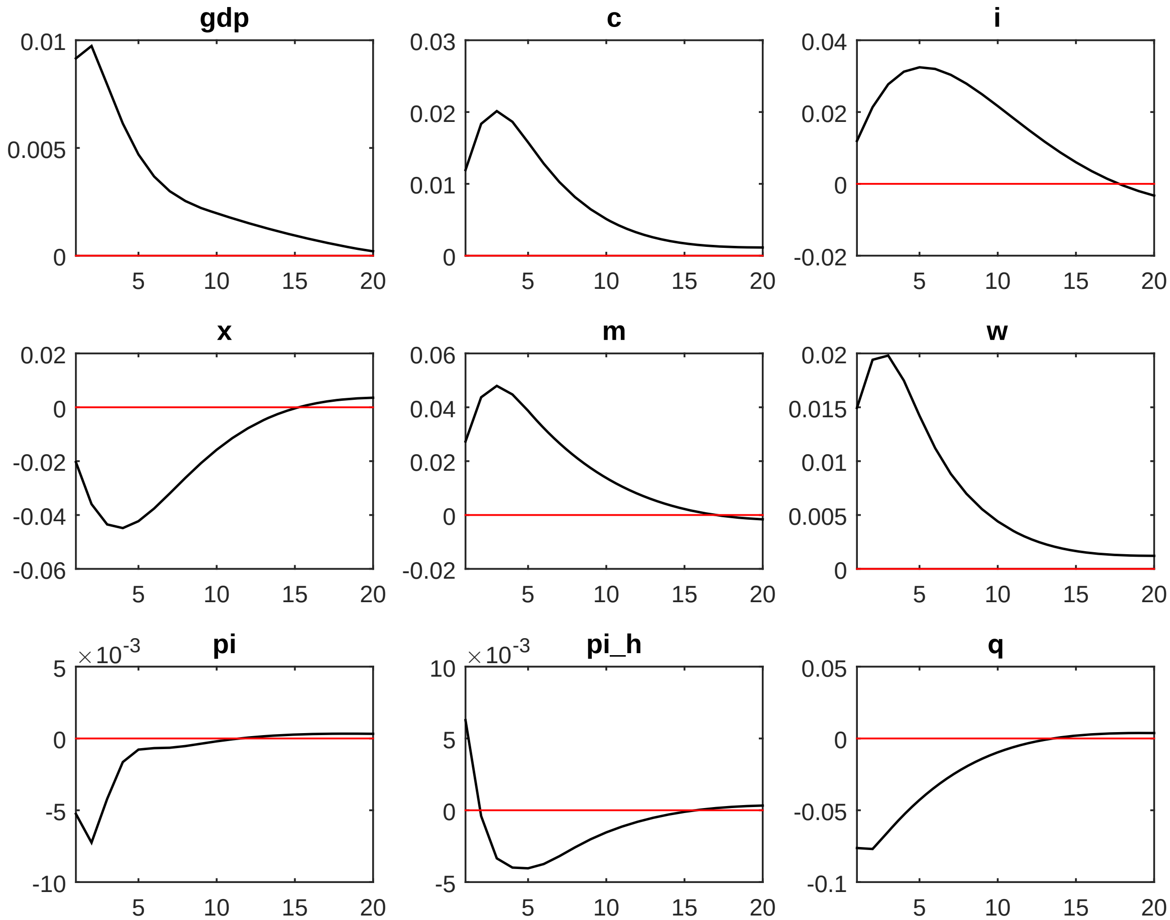

Figure 3.4: Impulse response functions following a simultaneous 1 s.d. shock to the oil price and capital flows

The effects of a positive oil price shock on real domestic variables are amplified in the presence of a concurrent capital inflow shock (Figure 3.4). The nominal exchange rate appreciates more strongly, despite increased central bank interventions and a lowered policy rate. As a consequence, prices for imported goods drop sharply in comparison to the separately occurring oil price shock. Although wages increase as in the former case, lower capital costs curb the increase in prices for domestically produced goods. Total consumer prices decrease on impact. Hence, there is no tradeoff for the monetary authority to stabilize either inflation or the exchange rate. The dimension of the nominal appreciation of the latter outweighs the reduction in the price level, so that the domestic currency appreciates in real terms, curbing non-oil exports and stimulating imports. As in the single-shock scenarios, domestic demand increases as a consequence of, both, higher commodity export revenues and ex-post real returns on bonds. The absolute effects on non-oil GDP, consumption, investment, non-oil exports and imports peak after three to five quarters and decrease gradually afterwards.

In absolute terms, simultaneously occurring shocks to oil prices and capital flows have the largest long-run effects on the real exchange rate, non-oil exports and imports as well as investment. Whereas both trade aggregates are affected to a comparable extent as in the single oil shock scenario, the impact on investment is lower. Due to a stronger nominal appreciation on impact and a faster return to the initial level in the quarters thereafter, the effect on the commodity price in local currency units and also the real exchange rate is much smaller and less persistent than without a concurrent capital flow shock.

3.5 Alternative monetary policy strategies

Based on the findings of the previous chapter, we analyze to which extent alternative monetary policy strategies could possibly limit the impact of external shocks, in particular to oil prices and capital flows, on the domestic economy. The variances of model variables following an oil price shock, a capital flow shock and both shocks occurring simultaneously, relative to the policy strategy in place, are presented in Tables 3.2, 3.7 and 3.8.

3.5.1 Inflation targeting

As a first policy alternative, a strategy is considered according to which the central bank adjusts its policy rate only in reaction to deviations of the inflation rate from its trend. The respective parameter ϕ_π is calibrated to its estimated value, whereas the exchange rate coefficient $\phi_{\Delta e}$ is set to zero. The central bank does not engage in any direct interventions on the foreign exchange market. Since its ability to control the exchange rate via the policy rate only is rather limited, the central bank takes lower (higher) import prices due to an appreciation (depreciation) as given and loosens (tightens) monetary policy to fuel (curb) domestic inflation to keep the overall price level rather stable.

Following an oil price shock, the central bank lowers its policy rate by more than under the actual strategy. However, it can not curb the effects on domestic variables, since the stronger appreciation of the domestic currency leads to even greater balance sheet effects and thus higher consumption, wages, domestic inflation and the total price index. The impact is less persistent, though, since the lower interest rate leads to a faster return of the exchange rate to its pre-shock level in light of a gradually weakening impulse from the oil price. Over the medium and long-term horizon, most domestic variables are less affected by the shock than under the policy in place. The higher impact on domestic prices and the total price level stems almost fully from the initial impulse.

In the presence of a capital inflow shock, the central bank cuts the interest by less than under the actual policy to limit deflationary pressures on the domestic prices, leading to an even stronger appreciation and higher imports in the very short-term. In contrast to the policy in place, the weaker policy reaction results in a less strong and persistent deviation from its steady-state so that the appreciation pressure on the domestic currency is remarkably lower in the course of the fast expiring shock. Consequently, the exchange rate overshoots its long-run trend by less with respectively weaker effects on the other variables. The total impact of the capital flow shock on the domestic economy under an inflation targeting strategy is remarkably lower compared to the actual policy.

In the case of simultaneously occurring shocks to oil prices and capital flows, the central bank does not have to react on impact, as falling import prices due to a very strong appreciation and higher domestic inflation following increased wage dynamics even. In light of the reduction of the initial shock impulses and the relatively loose monetary policy, the domestic currency appreciation quickly reverses, causing the central bank to raise its interest rate, as raising import prices increase total inflation. Its high persistence keeps the interest rate above its steady state and the exchange rate overvalued in real terms, with a negative impact on exports and a stimulus for imports. The relative variance of nearly all variables is nonetheless smaller under inflation targeting compared to the estimated policy in place. Total inflation is slightly stronger affected under the alternative strategy, in particular because of a strong increase in domestic prices on impact and a reversion of the exchange rate appreciation in the subsequent quarter.

3.5.2 Strict inflation targeting

Similar to the first policy alternative, we assume a strategy according to which the central bank reacts only to movements in the inflation rate. Contrary to the former alternative, however, we assume that the reaction is very strong. To capture this, the respective parameter is set to $\phi_\pi = \infty$. All other monetary policy parameters do not change compared to the moderate inflation targeting strategy.

By definition, the domestic inflation rate does not deviate from its trend, since the central bank adjusts its policy rate to whatever extent it takes to counter any shocks, with the respective effects on other domestic variables. Following an oil price shock that leads to an initial increase in the price level of domestically produced goods due to higher wages, the domestic interest rate increases by more, fueling a stronger appreciation of the domestic currency and a larger impact on exports and imports. Lower import prices compensate for the moderate increase in the domestic price level to stabilize total inflation. Except for the latter two variables, the home economy is affected stronger by oil price shocks compared to the policy in place.

In reaction to a capital inflow shock, the central bank lowers the policy rate to curb the effects of a stronger appreciation on prices. Consumption increases due to a decreased real interest rate, as do wages in light of a higher marginal rate of substitution between consumption and labor and consequently domestic prices. As under the current policy, the effects are not persistent and revert after less than one year. With capital flows returning to its trend, an enduringly lower interest rate and zero inflation cause the real exchange rate to overshoot its long-term level by even more than under the policy strategy in place. On the two-year horizon, most domestic variables are substantially more affected under strict inflation targeting. The larger imbalance leads, however, to a faster return to the steady state. In the long-run, only real wages are slightly more affected by this policy alternative, with all other domestic variables exhibiting a lower degree of impact.

Whereas the initial effect on inflation is the same on impact under both strategies, inflation targeting and strict inflation targeting differ in their policy reaction following the simultaneous disturbances to oil prices and capital flows. A lowered policy rate under the latter strategy curbs the currency's appreciation on impact and its reversion in the periods thereafter. Domestic prices increase only modestly, as lower capital costs more than outweigh the rise in wages. Consequently both, consumption and investment expenditures, are stimulated stronger. In the medium and long-run, the overall lower degree of real appreciation substantially reduces the volatility in most of the domestic variables, as compared to the actual policy strategy and the moderate inflation targeting alternative.

3.5.3 Hybrid inflation targeting

As a third policy alternative, we analyze a strategy according to which the central bank focuses primarily on movements of the inflation rate but also on deviations of output from its trend. Following Taylor (1993), we set the respective reaction coefficients to 1.5 and 0.5.

In the presence of an oil price shock, the central bank raises the interest rate only modestly to allow for a stronger appreciation of the domestic currency. This in turn has several positive effects on the authority's targeted variables: oil price revenues in domestic currency units increase by less than under the actual strategy, curbing the rise in domestic demand, wages and thus the domestic goods inflation. In addition, prices for imported goods fall more

1 Quarter	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	2.28	2.41	2.81	0.24	2.03
Consumption	1.13	1.70	1.06	0.66	1.02
Investment	0.39	0.44	0.52	0.30	1.01
Exports	0.91	0.79	1.10	0.29	1.53
Imports	1.23	1.36	1.27	0.48	1.34
Real wages	1.58	1.91	1.07	1.67	0.73
Inflation	0.00	0.00	4.77	23.15	14.77
Dom. prices	5.17	4.91	0.26	27.36	0.78
Real ER	2.67	2.33	3.19	0.11	2.66
4 Quarters	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	0.79	0.85	0.84	0.20	1.31
Consumption	0.46	0.55	0.60	0.28	1.11
Investment	0.30	0.30	0.46	0.33	0.95
Exports	0.49	0.41	0.65	0.35	1.22
Imports	0.49	0.47	0.63	0.30	1.18
Real wages	0.73	0.63	0.74	0.56	1.22
Inflation	1.11	0.00	1.66	7.05	4.84
Dom. prices	4.28	3.26	0.46	17.93	0.53
Real ER	0.99	0.86	1.22	0.20	1.61
8 Quarters	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	0.68	0.73	0.70	0.28	1.17
Consumption	0.41	0.46	0.58	0.39	1.00
Investment	0.36	0.34	0.57	0.50	0.89
Exports	0.51	0.42	0.69	0.50	1.13
Imports	0.45	0.42	0.62	0.42	1.07
Real wages	0.66	0.56	0.71	0.59	1.16
Inflation	1.13	0.00	1.67	7.04	4.98
Dom. prices	2.50	1.93	0.37	10.67	0.33
Real ER	0.89	0.77	1.12	0.30	1.49
∞	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	0.78	0.81	0.87	0.54	1.14
Consumption	0.64	0.65	0.93	0.78	1.00
Investment	0.64	0.58	1.01	1.01	0.88
Exports	0.70	0.59	0.94	0.80	1.11
Imports	0.62	0.56	0.85	0.70	1.06
Real wages	0.87	0.75	1.00	0.91	1.16
Inflation	1.12	0.00	1.87	7.25	4.98
Dom. prices	2.34	1.78	0.67	10.24	0.32
Real ER	0.95	0.82	1.20	0.40	1.47

Table 3.2: Variances following simultaneous shocks to oil prices and capital flows under inflation targeting (IT), strict inflation targeting (SIT), hybrid inflation targeting (HIT), a fixed exchange rate (FIX) and ruble price of oil targeting (ROIL), relative to current policy

sharply, limiting the increase in total inflation. On the other hand, the stronger currency appreciation holds true also in real terms, translating to a higher volatility of non-fuel exports and imports.

The reaction of the monetary policy to a capital inflow shock under hybrid inflation targeting is similar to the ordinary inflation targeting case, with the effects on most of the variables being almost identical. Simultaneously occurring shocks to the oil price and capital flows lead to a fall in the rate of total inflation, as import prices fall more sharply in light of a strongly appreciating currency, whereas domestic prices rise only moderately against the background of a modest increase in wages. As under the inflation targeting strategy, the fast reduction in capital flows and the return of the oil price to its pre-shock level, put depreciation pressure on the domestic currency in the subsequent quarters. The initial effects on prices reverse quickly leading to an increase in the real interest rate and consequently higher domestic demand. Over the medium and long-term, the strategy of hybrid inflation targeting does not outperform the previous two alternatives and does not appear to be superior to the policy in place.

3.5.4 Fixed exchange rate

This alternative policy is characterized by the central bank's strategy to fix its currency's exchange rate by conducting unlimited direct interventions on the foreign exchange market. Consequently, the reaction coefficient in the intervention rule is set to $\phi_{\Delta e,int} = \infty$. The interest rate is not used as a policy instrument, as in reality it cannot be set independently of the foreign exchange market operations. Since in the model specification it is assumed that the central bank is capable to fully sterilize its interventions, the latter do not have any effects on the former so that it remains at its steady state level.

Foreign capital shocks are completely offset by the monetary policy serving excess demand for and demanding excess supply of foreign currency via sales and purchase of its reserves. Domestic variables remain unaffected.

Shocks to the oil price, however, translate one-to-one to higher revenues quoted in domestic currency, stimulating consumption and total output. Trade aggregates are affected less, since the impact of the disturbance on the real exchange rate is modest. Absent this channel and with the oil price gradually returning to its pre-shock trend, the effects of its initial increase on income and spending decline. Except for the very short-term, the domestic economy as a whole is shielded better from a commodity price shock under an exchange rate peg, compared to the policy in place and different kinds of inflation targeting strategies.

However, with the exchange rate and thus prices of imported goods held constant, consumer prices are stronger affected by the higher volatility of the domestic price level.

Since shocks to foreign capital flows can be fully neutralized by central bank interventions, the effects of the disturbance in combination with a simultaneous oil price shock correspond exactly to the latter occurring independently. Relative to the outcome under alternative strategies, in which import prices drop following an even stronger appreciation to curb the total price level, consumer price inflation is even more affected under the peg regime, as higher wages push the domestic price level and monetary policy cannot be tightened to counter this development.

3.5.5 Ruble price of oil targeting

Finally, we analyze the alternative strategy of the CBR targeting the ruble price of oil, so that it intervenes to match the rate of exchange rate appreciation (depreciation) to the change in the price of oil on the world market. This policy alternative is motivated by Frankel (2005), who argues that countries that are specialized in exporting one particular commodity should fix its price in terms of the local currency since this would automatically accommodate shocks to the terms of trade. The strategy should provide a credible nominal anchor to monetary policy and be based on reliable 'now data', reducing problems associated with time-inconsistency. We implement the policy strategy by including the domestic currency price of oil in the intervention rule and setting the respective reaction coefficient to infinity.

As in the case of an exchange rate peg, foreign capital shocks are completely offset by the monetary policy, so that domestic variables remain unaffected.

Following a positive shock to the oil price, the central bank amplifies the exchange rate appreciation via foreign exchange interventions. Prices for imported goods drop sharply, causing the total price level to decrease. Imports soar against the background of the strong real appreciation, whereas demand for exports declines. Higher income fuels consumption expenditures and wage growth that subsequently translates to higher domestic prices. This consequently leads to an increase of the overall price index, since import prices recover in the light of the domestic currency's depreciation caused by the gradual return of the oil price to its pre-shock level. Even though the economy is hit much stronger by the shock in the short-term than under any other strategy, the long-run effects only slightly exceed those under the policy in place. However, this holds true only for temporary shocks to the oil price and consequently temporary real exchange rate misvaluations. As a strategy to primarily fend off short-term fluctuations, ruble price of oil targeting proves ineffective and even rather destabilizing. Herz et al. (2015) come to a similar conclusion.

Again, as in the case of exchange rate pegs, since shocks to foreign capital flows can be fully neutralized by central bank interventions, the effects of oil price shocks on the economy are the same independent of a contemporaneous capital flow shock. Also, relative effects compared to the policy in place and other alternatives do not differ substantially.

3.5.6 Alternative policy forecast error variance decomposition

After the analysis of the effects of shocks to oil prices and capital flows under different policy regimes, we turn our attention to how domestic variables are affected from all modeled disturbances under possible policy alternatives. Therefore, we simulate the model for the strategies presented in the preceding sections and compare the forecast error variance decompositions at different time horizons to the estimated policy in place. For reasons of consistency, we exclude the two monetary policy shocks in the model and adjust the deviations in the alternative scenarios respectively. Results are presented in the Tables 3.3, 3.9, 3.10, 3.11 and 3.12.

Compared to the monetary policy strategy in place, the relative impact of oil price shocks on the volatility of inflation and output can only be reduced at all horizons when adapting hybrid targeting. In addition, it most strongly increases the relative importance of technology shocks in describing the behavior of real variables, to comply with the theory of real business cycles. Also in line with theory, hybrid targeting of inflation and output leads to a tradeoff for the central bank in the presence of supply shocks and consequently a higher relative impact of these disturbance on the inflation rate compared to the current strategy.

As already proposed by the consideration of single capital flow shocks, the relative importance of these disturbances to fluctuations of nearly all domestic variables can substantially be reduced at all horizons by adapting any of the proposed policy alternatives. Analogously, however, in all of the three proposed inflation targeting regimes real GDP is affected stronger on impact.

Under a fixed exchange rate regime, capital flow shocks would be fully compensated by respective foreign exchange interventions and thus have no effect on domestic variables. However, oil price shocks would result in an amplification of their inherent impact on the exchange rate, imported prices and total inflation that the central bank cannot mitigate due to the abandonment of an independent monetary policy.

Ruble price of oil targeting proves inferior to the policy in place as well as the other alternatives. Whereas it offsets the impact on nominal exchange rate dynamics caused by

1 Quarter	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.9	-21.1	24.4	2.2	-8.1	-5.1	-16.8	4.7	-1.8	0.5
Consumption	-3.0	-2.6	0.0	-3.2	1.2	1.8	0.2	1.2	-1.1	0.0
Investment	0.0	-0.4	-0.6	1.7	-0.3	1.0	0.0	-2.1	0.3	0.0
Exports	-0.2	-18.0	-3.8	-6.6	25.7	-13.3	1.2	0.2	-3.0	-0.3
Imports	-4.0	-14.0	1.9	0.9	3.0	-7.0	-0.1	1.0	0.1	0.2
Real wages	-13.3	-11.9	-10.8	17.7	-24.4	-1.7	0.1	18.1	1.1	-0.1
Inflation	-15.3	-28.8	-23.2	20.2	-21.2	1.0	0.4	21.3	1.7	-0.1
Dom. Prices	-13.3	-11.9	-10.8	17.7	-24.4	-1.7	0.1	18.1	1.1	-0.1
Real ER	-0.3	-83.2	13.4	-2.5	3.8	-18.5	1.0	5.6	-3.6	0.8
4 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-0.7	-7.6	1.4	4.1	-6.3	1.6	-3.5	3.5	-0.9	0.1
Consumption	-1.3	-6.3	-7.0	16.9	2.4	-11.9	-0.4	-3.0	2.9	0.1
Investment	-0.4	-0.2	-0.4	2.7	-1.0	0.9	0.0	-2.6	0.5	0.0
Exports	-3.5	-7.2	-8.2	-7.1	30.2	-12.1	1.3	-1.2	-2.8	-0.1
Imports	-2.9	-13.0	-14.8	11.6	-12.6	-0.8	0.1	14.5	2.1	0.0
Real wages	-3.5	-3.2	-3.6	0.0	-1.8	2.1	0.2	2.9	0.3	0.1
Inflation	-14.7	-29.5	-26.5	21.2	-19.7	-0.6	0.6	24.0	1.4	-0.4
Dom. Prices	-12.3	-12.9	-12.4	18.4	-23.8	-3.3	0.3	20.1	0.8	-0.2
Real ER	-1.6	-35.0	9.5	-4.2	8.6	-16.2	1.2	3.7	-3.3	0.8
8 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.5	-3.8	0.8	4.0	-6.5	1.8	-1.6	1.8	-0.2	0.0
Consumption	-3.9	-4.6	-4.7	20.2	-2.0	-11.7	-0.3	-4.2	2.8	-0.1
Investment	-1.2	-0.2	-0.1	3.5	-2.3	0.5	0.0	-2.0	0.5	-0.1
Exports	-9.5	-3.8	-2.7	-7.8	25.0	-8.7	1.2	-4.7	-2.2	-0.2
Imports	-8.7	-7.1	-7.2	11.7	-24.1	3.5	0.1	14.5	1.9	-0.4
Real wages	-5.3	-2.8	-2.6	5.4	-3.8	0.6	0.1	0.6	-0.3	0.0
Inflation	-14.8	-29.0	-26.0	21.4	-19.7	-1.7	0.6	25.0	1.2	-0.7
Dom. Prices	-12.1	-12.6	-12.3	18.7	-23.5	-4.8	0.3	21.3	0.6	-0.4
Real ER	-6.6	-24.1	10.8	-5.2	6.7	-12.0	1.2	0.8	-2.7	0.4
∞	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-2.7	-3.8	-1.1	4.4	-6.2	0.6	-0.9	3.3	0.0	-0.2
Consumption	-6.8	-6.0	-6.5	14.3	-3.1	-6.4	-0.1	1.2	1.0	-0.3
Investment	-2.9	-1.7	-1.9	4.7	-3.5	0.1	0.0	0.3	0.6	-0.2
Exports	-12.5	-8.9	-8.9	-6.6	29.0	-4.8	1.0	-7.9	-1.3	-0.5
Imports	-13.1	-11.2	-12.4	11.8	-19.3	3.6	0.2	15.4	1.7	-0.8
Real wages	-7.1	-4.6	-4.8	4.9	-3.5	0.0	0.1	3.9	-0.4	-0.2
Inflation	-15.1	-29.0	-26.4	21.7	-19.7	-1.7	0.6	25.2	1.1	-0.8
Dom. Prices	-12.5	-12.8	-12.6	18.9	-23.6	-4.6	0.3	21.5	0.5	-0.6
Real ER	-9.4	-22.4	4.8	-5.2	12.4	-8.3	1.1	-2.9	-1.9	0.0

Table 3.3: Forecast error variance decomposition at different horizons under hybrid inflation targeting, in percentage point deviations from the current policy, adjusted for absence of monetary policy shocks

non-fundamental capital flows, it induces exchange rate fluctuations according to movements in oil prices that affect the domestic economy via an increased volatility of absolute and relative prices.

3.6 Conclusion

Russian monetary policy has been challenged by large and continuous private capital outflows and a sharp drop in oil prices during 2014, with both ongoings having put a significant depreciation pressure on the ruble. In order to mitigate the impact on its currency, the central bank repeatedly raised its key policy rate and directly intervened on the foreign exchange market. However, its policy measures could not prevent a strong depreciation of the ruble, while raised interest rates might have posed an additional obstacle for the already weak economy. This work estimates a small open economy model for Russia, featuring an oil price sector and extended by a specification of the foreign exchange market to correctly account for systematic central bank interventions. We find that shocks to the oil price and private capital flows substantially affect domestic variables, such as inflation, output and the exchange rate. Simulations of the model for the estimated actual strategy and five alternative regimes suggest that the vulnerability of the Russian economy to external shocks can be substantially lowered by adopting some form of inflation targeting strategy. Foreign exchange intervention-based policy strategies to target the nominal exchange rate or the ruble price of oil, on the other hand, prove inferior to the policy in place, in particular because of the lacking ability of conducting independent monetary policy via the interest rate. However, in the presence of non-fundamental capital flow shocks, interventions may be helpful to offset destabilizing effects from their impact on the exchange rate. Although these implications do not qualitatively differ from the ones argued for in comparable studies in the past, the analysis in this work has been conducted by properly accounting for foreign exchange interventions of the central bank and also by introducing non-fundamental capital flows that have a direct impact on the exchange rate and thus on potential policy strategies that aim at a stabilization of the latter. Even though capital flows are regarded as non-fundamental in the sense that their dynamics are not explained by other model variables, large and continuous capital outflows are not random in reality. Since our analysis finds them to strongly affect the domestic economy, any political arbitrariness as well as legal and political uncertainty that might cause them should be regarded as obstacles to a sound economic development.

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Appendix B: Log-linearized model equations

Marginal utility of consumption:

$$\lambda_t = \left(-\left(\frac{\sigma_c}{1-h}\right)\right)\,(c_t - h\,c_{t-1}) + \varepsilon_t^b \tag{3.66}$$

Marginal utility of savings:

$$\lambda_t = r_t + \lambda_{t+1} - \pi_{t+1} - \xi\,b_t \tag{3.67}$$

Wage dynamics:

$$\begin{aligned} w_t = \; & \tfrac{\beta}{1+\beta}\,w_{t+1} + \tfrac{1}{1+\beta}\,w_{t-1} + \pi_{t+1}\,\tfrac{\beta}{1+\beta} + \tfrac{1+\beta\,\delta^w}{1+\beta}\,\pi_t + \tfrac{\delta^w}{1+\beta}\,\pi_{t-1} - \tfrac{1}{1+\beta}\,\tfrac{(1-\beta\,\theta^w)\,(1-\theta^w)}{\theta^w\,\left(1+\frac{(1+\lambda^w)\,\varphi}{\lambda^w}\right)} \\ & \times \left(w_t - \varphi\,l_t - \tfrac{\sigma}{1-h}\,(c_t - h\,c_{t-1}) - \varepsilon_t^l\right) \end{aligned} \tag{3.68}$$

Shadow price of capital:

$$t_t = \xi\,b_t + \pi_{t+1} - r_t + \beta\,\left(\bar{r}^k\,r_{t+1}^k + (1-\delta)\,t_{t+1}\right) \tag{3.69}$$

Investment Euler equation:

$$i_t = f_t\,\frac{1}{(1+\beta)\,\varkappa} + \frac{1}{1+\beta}\,i_{t-1} + \frac{\beta}{1+\beta}\,i_{t+1} + \frac{1}{1+\beta}\,\left(\beta\,\varepsilon_{t+1}^i - \varepsilon_t^i\right) \tag{3.70}$$

Capital law of motion:

$$k_t = (1-\delta)\,k_{t-1} + \delta\,i_t \tag{3.71}$$

Labor demand:

$$l_t = k_{t-1} + (1+\omega)\,r_t^k - w_t \tag{3.72}$$

Marginal cost:

$$mc_t = w_t\,(1-\psi) + r_t^k\,\psi - a_t \tag{3.73}$$

Marginal cost exported goods:

$$mc_t^x = mc_t - q_t - p_t^x \tag{3.74}$$

Marginal cost imported goods:

$$mc_t^m = q_t - p_t^m \tag{3.75}$$

Domestic goods inflation:

$$\pi_t^h - \delta^h\,\pi_{t-1}^h = \kappa_h\,\left(mc_t - p_t^h\right) + \beta\,\left(\pi_{t+1}^h - \pi_t^h\,\delta^h\right) \tag{3.76}$$

with:

$$\kappa_h = \frac{\left(1-\theta^h\right)\,\left(1-\theta^h\,\beta\right)}{\theta^h} \tag{3.77}$$

Exported goods inflation:

$$\pi_t^x - \delta^x\,\pi_{t-1}^x = mc_t^x\,\kappa_x + \beta\,\left(\pi_{t+1}^x - \pi_t^x\,\delta^x\right) \tag{3.78}$$

with:

$$\kappa_x = \frac{(1-\theta^x)\,(1-\beta\,\theta^x)}{\theta^x} \tag{3.79}$$

Imported goods inflation:

$$\pi_t^m - \delta^m\,\pi_{t-1}^m = mc_t^m\,\kappa_m + \beta\,\left(\pi_{t+1}^m - \pi_t^m\,\delta^m\right) \tag{3.80}$$

with:

$$\kappa_m = \frac{(1-\theta^m)\,(1-\beta\,\theta^m)}{\theta^m} \tag{3.81}$$

Consumer price inflation:

$$\pi_t = \alpha\,\pi_t^h + (1-\alpha)\,\pi_t^m \tag{3.82}$$

Price level domestic goods:

$$p_t^h = p_t^m\,\left(-\left(\frac{1-\alpha}{\alpha}\right)\right) \tag{3.83}$$

Price level exported goods:

$$p_t^x = \pi_t^x + p_{t-1}^x - \pi_t^* \tag{3.84}$$

Price level imported goods:

$$p_t^m = \pi_t^m + p_{t-1}^m - \pi_t \tag{3.85}$$

GDP deflator:

$$p_t^y = \phi_x\,(q_t + p_t^x) + \phi_o\,\left(q_t + p_t^O\right) - p_t^m\,\phi_m \tag{3.86}$$

Domestic production:

$$y_t = a_t + k_{t-1}\,\psi + r_t^k\,\omega\,\psi + l_t\,(1-\psi) \tag{3.87}$$

Demand for domestic goods:

$$y_t^h = (-\eta)\,p_t^h + \left(\frac{\phi_c}{\phi_c+\phi_i}\right)c_t + \left(\frac{\phi_i}{\phi_c+\phi_i}\right)i_t \tag{3.88}$$

Demand for exported goods:

$$x_t = (-\eta^x)\,p_t^x + y_t^* \tag{3.89}$$

Demand for imported goods:

$$m_t = (-\eta)\,p_t^m + \left(\frac{\phi_c}{\phi_c+\phi_i}\right)c_t + \left(\frac{\phi_i}{\phi_c+\phi_i}\right)i_t \tag{3.90}$$

Non-oil GDP:

$$y_t = \frac{1}{1-\phi_o}\,(\phi_c c_t + \phi_i i_t + \phi_x\,x_t - \phi_m\,m_t) + \varepsilon_t^g \tag{3.91}$$

Total GDP:

$$gdp_t = \phi_o\,(q_t + p_t^o) + (1-\phi_o)\,\left(y_t + p_t^h\right) - p_t^y \tag{3.92}$$

Total economy budget constraint:

$$\phi_b\,\left(b_t - \frac{1}{\beta}\,b_{t-1}\right) = \phi_o\,\left(q_t + p_t^O\right) + \phi_x\,(q_t + p_t^x + x_t) - \phi_m\,(p_t^m + m_t) + \frac{\phi_b}{\beta}\,(r_{t-1} - \pi_t) \tag{3.93}$$

Real exchange rate:

$$q_t = \pi_t^* + q_{t-1} + \Delta e_t - \pi_t \tag{3.94}$$

Uncovered interest parity condition:

$$\Delta e_{t+1} = r_t - r_t^* + \gamma \sigma_{\Delta e}^2 \left(\omega_t^* + \omega_t^{*,CB} \right) \tag{3.95}$$

Monetary policy rule:

$$r_t = r_{t-1}\, \rho_r + (1 - \rho_r)\, (\pi_t\, \phi_\pi + \Delta e_t\, \phi_{\Delta e}) + \eta_t^m \tag{3.96}$$

Central bank intervention rule:

$$\omega_t^{*,CB} = \phi_{\Delta e, int} \Delta e_t + \eta_t^{int} \tag{3.97}$$

Foreign capital flows:

$$\omega_t^* = \rho_{\omega^*}\, \omega_{t-1}^* + \eta_t^{\omega^*} \tag{3.98}$$

Oil price:

$$p_t^o = \rho_o\, p_{t-1}^o + \eta_t^o \tag{3.99}$$

Technology shock

$$a_t = \rho_a\, a_{t-1} + \eta_t^a \tag{3.100}$$

Preference shock:

$$\varepsilon_t^b = \rho_b\, \varepsilon_{t-1}^b + \eta_t^b \tag{3.101}$$

Government spending shock:

$$\varepsilon_t^g = \rho_g\, \varepsilon_{t-1}^g + \eta_t^g \tag{3.102}$$

Investment shock:

$$\varepsilon_t^i = \rho_i\, \varepsilon_{t-1}^i + \eta_t^i \tag{3.103}$$

Labor supply shock:

$$\varepsilon_t^l = \rho_l\, \varepsilon_{t-1}^l + \eta_t^l \tag{3.104}$$

And the variables of the foreign block outlined in (3.57).

Appendix C: Tables and figures

Parameter		Value
Discount parameter	β	0.9900
Depreciation rate	δ	0.0250
Share of capital in production	ψ	1/3
Net wage markup	λ^w	0.1500
Share of foreign goods in consumption	α	0.2300
Nominal ER depreciation variance	$\sigma^2_{\Delta e}$	0.0065
Risk aversion parameter	γ	200.00
Portfolio adjustment cost	ψ^b	0.1000
Steady-state consumption to GDP	ϕ_c	0.5000
Steady-state investment to GDP	ϕ_i	0.2000
Steady-state non-fuel exports to GDP	ϕ_x	0.1200
Steady-state imports to GDP	ϕ_m	0.1600
Steady-state fuel exports to GDP	ϕ_o	0.1700
Steady-state reserves to GDP	ϕ_b	0.9000

Table 3.4: Calibrated parameter and steady state values

Parameter		**Distribution**	**Mean**	**St. Dev.**
Relative risk aversion	σ	Gamma	1.20	0.40
Inverse labor supply elasticity	ϕ	Gamma	1.50	0.75
Habit persistence	h	Beta	0.50	0.25
Fixed cost	φ	Gamma	1.45	0.25
Capital utilization adj. Cost	ω	Gamma	0.20	0.08
Investment adj. Cost	$\varkappa$	Gamma	4.00	0.75
Elasticity home/foreign goods	η	Gamma	1.00	0.75
Elasticity foreign/home goods abroad	η^x	Gamma	1.00	0.75
Calvo domestic goods	θ^h	Beta	0.50	0.10
Calvo exported goods	θ^x	Beta	0.50	0.10
Calvo imported goods	θ^m	Beta	0.50	0.10
Calvo wages	θ^w	Beta	0.50	0.10
Indexation domestic goods	δ^h	Beta	0.50	0.25
Indexation exported goods	δ^x	Beta	0.50	0.25
Indexation imported goods	δ^m	Beta	0.50	0.25
Indexation wages	δ^w	Beta	0.50	0.25
Interest rate smoothing	ρ_r	Beta	0.80	0.10
Taylor coefficient inflation	ϕ_π	Gamma	1.50	0.30
Taylor coefficient exch. Rate	$\phi_{\Delta e}$	Gamma	0.50	0.13
Intervention coefficient exch. Rate	$\phi_{\Delta e,int}$	Gamma	0.50	0.13
AR(1) parameter oil price	ρ_{po}	Beta	0.20	0.15
AR(1) parameter capital flows	ρ_{ω^*}	Beta	0.40	0.15
AR(1) parameter technology	ρ_a	Beta	0.80	0.10
AR(1) parameter gov. Spending	ρ_g	Beta	0.80	0.10
AR(1) parameter preferences	ρ_b	Beta	0.80	0.10
AR(1) parameter labor supply	ρ_l	Beta	0.80	0.10
AR(1) parameter investment	ρ_i	Beta	0.80	0.10
S.d. monetary policy shock	η^m	Inv. Gamma	0.01	2.00
S.d. capital flow shock	η^{ω^*}	Inv. Gamma	0.05	2.00
S.d. intervention shock	η^{int}	Inv. Gamma	0.15	2.00
S.d. oil price shock	η^{po}	Inv. Gamma	0.15	2.00
S.d. technology shock	η^a	Inv. Gamma	0.01	2.00
S.d. gov. spending shock	η^g	Inv. Gamma	0.01	2.00
S.d. preference shock	η^b	Inv. Gamma	0.01	2.00
S.d. labor supply shock	η^l	Inv. Gamma	0.01	2.00
S.d. investment shock	η^i	Inv. Gamma	0.01	2.00
S.d. foreign output shock	η^{y^*}	Inv. Gamma	0.01	2.00
S.d. foreign inflation shock	η^{π^*}	Inv. Gamma	0.01	2.00
S.d. foreign interest shock	η^{r^*}	Inv. Gamma	0.01	2.00

Table 3.5: Prior means and standard deviations

Parameter		Mean	90% Prob.	
Relative risk aversion	σ	1.0349	0.7147	1.3539
Inverse labor supply elasticity	ϕ	0.0711	0.0116	0.1280
Habit persistence	h	0.3953	0.2335	0.5521
Fixed cost	φ	1.4509	1.0455	1.8472
Capital utilization adj. Cost	ω	0.1707	0.0617	0.2755
Investment adj. Cost	$\varkappa$	6.2959	4.8374	7.6526
Elasticity home/foreign goods	η	0.4222	0.1424	0.6852
Elasticity foreign/home goods abroad	η^x	0.8754	0.4704	1.2660
Calvo domestic goods	θ^h	0.2236	0.1471	0.2984
Calvo exported goods	θ^x	0.6667	0.5673	0.7684
Calvo imported goods	θ^m	0.3886	0.2695	0.5030
Calvo wages	θ^w	0.1196	0.0658	0.1728
Indexation domestic goods	δ^h	0.2584	0.0030	0.5105
Indexation exported goods	δ^x	0.1760	0.0008	0.3743
Indexation imported goods	δ^m	0.5602	0.1793	0.9702
Indexation wages	δ^w	0.1379	0.0005	0.2952
Interest rate smoothing	ρ_r	0.9324	0.9078	0.9566
Taylor coefficient inflation	ϕ_π	1.4436	0.9737	1.8873
Taylor coefficient exch. Rate	$\phi_{\Delta e}$	0.5017	0.3108	0.6859
Intervention coefficient exch. Rate	$\phi_{\Delta e,int}$	0.8957	0.7217	1.0689
AR(1) parameter oil price	ρ_{po}	0.7943	0.7289	0.8581
AR(1) parameter capital flows	ρ_{ω^*}	0.2354	0.1248	0.3470
AR(1) parameter technology	ρ_a	0.8959	0.8389	0.9542
AR(1) parameter gov. Spending	ρ_g	0.7591	0.6309	0.8890
AR(1) parameter preferences	ρ_b	0.7937	0.7341	0.8563
AR(1) parameter labor supply	ρ_l	0.7338	0.5826	0.8853
AR(1) parameter investment	ρ_i	0.7777	0.6938	0.8618
S.d. monetary policy shock	η^m	0.0066	0.0054	0.0078
S.d. capital flow shock	η^{ω^*}	0.0615	0.0524	0.0707
S.d. intervention shock	η^{int}	0.0841	0.0706	0.0973
S.d. oil price shock	η^{po}	0.1446	0.1232	0.1657
S.d. technology shock	η^a	0.0184	0.0142	0.0224
S.d. gov. spending shock	η^g	0.0120	0.0102	0.0139
S.d. preference shock	η^b	0.0837	0.0683	0.0978
S.d. labor supply shock	η^l	0.0307	0.0222	0.0388
S.d. investment shock	η^i	0.0802	0.0561	0.1037
S.d. foreign output shock	η^{y^*}	0.0041	0.0035	0.0047
S.d. foreign inflation shock	η^{π^*}	0.0039	0.0033	0.0044
S.d. foreign interest shock	η^{r^*}	0.0012	0.0011	0.0014

Table 3.6: Posterior means and probability distributions

1 Quarter	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	1.41	2.28	0.43	1.33	11.06
Consumption	1.16	0.81	1.11	1.42	2.20
Investment	0.74	1.21	1.05	0.73	2.45
Exports	1.07	1.87	1.46	0.88	4.73
Imports	1.16	1.20	1.24	1.21	3.39
Real wages	1.19	0.47	0.78	1.48	0.64
Inflation	1.17	0.00	0.21	1.77	1.13
Dom. prices	1.20	0.10	0.42	1.61	0.05
Real ER	1.68	5.04	3.20	1.07	26.01
4 Quarters	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	0.93	1.79	0.37	0.91	5.86
Consumption	0.93	1.61	1.38	0.94	3.65
Investment	0.64	1.20	1.00	0.61	1.76
Exports	0.91	1.57	1.23	0.74	2.63
Imports	0.91	1.55	1.27	0.82	3.26
Real wages	1.09	1.21	1.10	1.08	2.36
Inflation	1.22	0.00	0.20	1.78	1.22
Dom. prices	1.22	0.13	0.42	1.59	0.05
Real ER	1.05	2.11	1.56	0.82	6.48
8 Quarters	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	0.68	1.29	0.38	0.70	2.96
Consumption	0.76	1.32	1.15	0.75	1.95
Investment	0.60	1.08	0.92	0.58	1.02
Exports	0.82	1.39	1.08	0.67	1.50
Imports	0.76	1.30	1.07	0.68	1.75
Real wages	0.94	1.22	1.04	0.87	1.70
Inflation	1.18	0.00	0.22	1.76	1.24
Dom. prices	1.19	0.13	0.44	1.58	0.05
Real ER	0.87	1.63	1.23	0.69	3.48
∞	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	0.70	1.18	0.67	0.75	1.57
Consumption	0.85	1.39	1.26	0.84	1.08
Investment	0.67	1.10	0.99	0.65	0.57
Exports	0.88	1.44	1.12	0.72	1.00
Imports	0.80	1.32	1.11	0.73	1.11
Real wages	0.99	1.41	1.15	0.88	1.12
Inflation	1.14	0.00	0.31	1.75	1.21
Dom. prices	1.14	0.13	0.50	1.55	0.05
Real ER	0.89	1.58	1.20	0.71	2.61

Table 3.7: Variances following a shock to oil prices under inflation targeting (IT), strict inflation targeting (SIT), hybrid inflation targeting (HIT), a fixed exchange rate (FIX) and ruble price of oil targeting (ROIL), relative to current policy

1 Quarter	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	3.08	2.51	5.96	0.00	0.00
Consumption	1.05	4.67	0.98	0.00	0.00
Investment	0.04	0.01	0.03	0.00	0.00
Exports	0.71	0.07	0.70	0.00	0.00
Imports	1.37	1.67	1.34	0.00	0.00
Real wages	2.08	102.65	2.17	0.00	0.00
Inflation	0.72	0.00	0.69	0.00	0.00
Dom. prices	0.51	0.08	0.48	0.00	0.00
Real ER	3.20	1.41	3.19	0.00	0.00
4 Quarters	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	1.03	0.94	1.97	0.00	0.00
Consumption	0.18	0.44	0.17	0.00	0.00
Investment	0.05	0.96	0.07	0.00	0.00
Exports	0.15	0.61	0.15	0.00	0.00
Imports	0.24	0.45	0.23	0.00	0.00
Real wages	0.21	1.15	0.21	0.00	0.00
Inflation	0.60	0.00	0.59	0.00	0.00
Dom. prices	0.41	0.17	0.39	0.00	0.00
Real ER	1.63	0.93	1.62	0.00	0.00
8 Quarters	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	1.04	1.11	1.96	0.00	0.00
Consumption	0.26	0.92	0.27	0.00	0.00
Investment	0.51	3.99	0.60	0.00	0.00
Exports	0.36	2.31	0.36	0.00	0.00
Imports	0.36	1.21	0.37	0.00	0.00
Real wages	0.35	1.90	0.35	0.00	0.00
Inflation	0.60	0.00	0.59	0.00	0.00
Dom. prices	0.41	0.17	0.38	0.00	0.00
Real ER	1.60	1.15	1.60	0.00	0.00
∞	**IT**	**SIT**	**HIT**	**FIX**	**ROIL**
Real GDP	0.67	0.86	1.23	0.00	0.00
Consumption	0.19	0.79	0.21	0.00	0.00
Investment	0.14	0.81	0.16	0.00	0.00
Exports	0.17	0.97	0.16	0.00	0.00
Imports	0.20	0.78	0.21	0.00	0.00
Real wages	0.23	1.23	0.22	0.00	0.00
Inflation	0.58	0.00	0.58	0.00	0.00
Dom. prices	0.39	0.16	0.37	0.00	0.00
Real ER	1.16	0.93	1.15	0.00	0.00

Table 3.8: Variances following a shock to foreign capital flows under inflation targeting (IT), strict inflation targeting (SIT), hybrid inflation targeting (HIT), a fixed exchange rate (FIX) and ruble price of oil targeting (ROIL), relative to current policy

1 Quarter	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.9	-21.1	18.9	-4.1	0.7	-0.7	-9.2	-4.1	-1.9	0.4
Consumption	-3.0	-2.6	0.1	-1.4	1.7	-0.1	0.0	0.3	-0.6	0.0
Investment	0.0	-0.4	-0.5	0.2	-0.6	1.1	0.0	-0.2	0.1	0.0
Exports	-0.2	-18.0	-4.9	0.9	4.4	-0.8	0.0	0.9	-0.1	-0.4
Imports	-4.0	-14.0	2.9	-1.3	2.4	-1.8	0.0	-2.1	-0.3	0.2
Real wages	-13.3	-11.9	-6.7	0.1	3.6	2.3	0.0	-0.1	0.5	0.4
Inflation	-15.3	-28.8	-8.6	0.1	3.1	3.9	0.0	-0.2	0.7	1.0
Dom. Prices	-13.3	-11.9	-6.7	0.1	3.6	2.3	0.0	-0.1	0.5	0.4
Real ER	-0.3	-83.2	17.8	-1.6	-4.8	-10.4	-0.1	0.1	-1.9	0.8

4 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-0.7	-7.6	0.1	0.1	-0.7	1.3	-0.3	-1.2	0.5	0.2
Consumption	-1.3	-6.3	-6.6	3.1	0.2	-0.1	0.1	0.8	2.4	0.1
Investment	-0.4	-0.2	-0.4	0.3	-1.4	1.4	0.0	-0.1	0.2	0.0
Exports	-3.5	-7.2	-8.3	1.1	6.0	-0.3	0.0	1.3	0.0	0.2
Imports	-2.9	-13.0	-12.1	1.9	4.9	1.1	0.0	2.4	1.4	0.4
Real wages	-3.5	-3.2	-3.5	-0.4	2.3	0.7	0.0	0.6	0.2	0.1
Inflation	-14.7	-29.5	-12.0	0.3	5.6	4.4	0.0	-0.1	0.8	0.9
Dom. Prices	-12.3	-12.9	-8.6	0.3	5.2	2.4	0.0	-0.1	0.5	0.3
Real ER	-1.6	-35.0	10.8	-0.5	-5.2	-5.2	0.0	0.4	-0.9	0.7

8 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.5	-3.8	0.1	0.9	-2.8	1.7	-0.3	0.0	0.5	0.0
Consumption	-3.9	-4.6	-4.2	5.4	-3.8	-0.5	0.1	0.5	2.6	-0.1
Investment	-1.2	-0.2	-0.1	0.6	-2.7	1.5	0.0	0.7	0.2	-0.1
Exports	-9.5	-3.8	-2.7	0.6	1.6	-0.5	0.0	1.1	-0.1	-0.1
Imports	-8.7	-7.1	-5.1	2.7	-5.6	2.5	0.0	4.4	1.1	-0.1
Real wages	-5.3	-2.8	-2.4	1.6	-0.6	0.7	0.0	0.5	0.2	0.0
Inflation	-14.8	-29.0	-11.6	0.3	5.2	4.5	0.0	0.1	0.8	0.6
Dom. Prices	-12.1	-12.6	-8.5	0.3	4.9	2.5	0.0	0.1	0.5	0.2
Real ER	-6.6	-24.1	11.9	-0.6	-8.5	-2.7	0.0	0.0	-0.5	0.4

∞	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-2.7	-3.8	-1.4	1.5	-3.2	0.9	-0.1	2.2	0.4	-0.1
Consumption	-6.8	-6.0	-6.0	4.8	-1.1	-0.3	0.1	1.1	1.6	-0.2
Investment	-2.9	-1.7	-1.8	1.0	-3.7	1.3	0.0	3.3	0.2	-0.2
Exports	-12.5	-8.9	-9.0	1.9	5.2	0.3	0.0	2.2	0.1	-0.5
Imports	-13.1	-11.2	-10.6	2.8	0.0	2.0	0.0	5.6	0.8	-0.5
Real wages	-7.1	-4.6	-4.4	1.9	1.7	0.3	0.0	0.4	0.2	-0.1
Inflation	-15.1	-29.0	-11.8	0.4	4.8	5.0	0.0	0.2	0.9	0.6
Dom. Prices	-12.5	-12.8	-8.8	0.4	4.2	3.4	0.0	0.1	0.6	0.1
Real ER	-9.4	-22.4	4.7	0.3	-3.7	-0.9	0.0	-0.2	-0.2	-0.1

Table 3.9: Forecast error variance decomposition at different horizons under inflation targeting, in percentage point deviations from the current policy, adjusted for absence of monetary policy shocks

1 Quarter	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.9	-21.1	12.6	-6.1	7.2	3.1	-8.9	-4.9	-3.3	0.2
Consumption	-3.0	-2.6	7.4	8.7	-2.6	-20.8	0.3	-0.2	7.2	0.1
Investment	0.0	-0.4	-0.6	-0.3	0.6	-0.8	0.0	1.2	-0.1	0.0
Exports	-0.2	-18.0	-17.4	3.1	2.6	12.4	0.1	0.3	2.4	-3.5
Imports	-4.0	-14.0	5.9	-0.5	3.4	-6.9	0.0	-2.4	0.3	0.2
Real wages	-13.3	-11.9	-1.7	0.9	3.7	-2.8	0.0	0.5	-0.3	-0.3
Inflation	-15.3	-28.8	2.6	6.8	-19.7	8.4	0.3	-0.4	2.5	-0.7
Dom. Prices	-13.3	-11.9	-1.7	0.9	3.7	-2.8	0.0	0.5	-0.3	-0.3
Real ER	-0.3	-83.2	-31.7	4.2	8.8	15.0	0.1	0.6	3.0	0.0
4 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-0.7	-7.6	-0.2	-3.7	6.8	-0.2	1.0	-2.0	-1.7	0.0
Consumption	-1.3	-6.3	-4.7	-5.9	8.0	3.8	-0.1	1.2	-2.2	-0.1
Investment	-0.4	-0.2	0.0	-0.6	1.1	-2.9	0.0	2.8	-0.3	-0.1
Exports	-3.5	-7.2	-6.7	2.2	-7.0	11.5	0.1	-0.4	2.2	-1.9
Imports	-2.9	-13.0	-10.4	-5.1	17.2	6.8	-0.1	-5.9	-2.2	-0.3
Real wages	-3.5	-3.2	0.4	-5.9	3.4	1.0	-0.1	0.7	0.5	-0.1
Inflation	-14.7	-29.5	-0.7	10.7	-18.3	6.4	0.4	-0.2	2.5	-0.9
Dom. Prices	-12.3	-12.9	6.6	0.1	2.9	-8.2	0.0	0.5	-1.3	-0.5
Real ER	-1.6	-35.0	-18.6	3.1	0.0	12.9	0.1	0.2	2.5	-0.2
8 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.5	-3.8	0.7	-1.9	2.9	-1.2	0.7	0.0	-1.0	-0.1
Consumption	-3.9	-4.6	-0.9	-7.6	5.5	5.3	-0.1	0.9	-2.8	-0.3
Investment	-1.2	-0.2	0.8	-0.7	1.0	-4.1	0.0	3.6	-0.4	-0.1
Exports	-9.5	-3.8	1.6	1.6	-13.6	11.1	0.1	-1.8	2.1	-1.2
Imports	-8.7	-7.1	0.7	-4.2	9.0	1.1	0.0	-4.4	-1.6	-0.6
Real wages	-5.3	-2.8	2.5	-8.8	2.6	2.9	-0.1	0.2	0.8	-0.1
Inflation	-14.8	-29.0	-0.2	10.8	-18.3	6.2	0.4	-0.2	2.5	-1.2
Dom. Prices	-12.1	-12.6	6.1	0.1	2.7	-7.5	0.0	0.4	-1.2	-0.6
Real ER	-6.6	-24.1	-9.3	2.4	-7.5	12.9	0.1	-0.8	2.5	-0.3
∞	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-2.7	-3.8	-0.3	-1.3	2.8	-3.5	0.6	2.6	-0.8	-0.1
Consumption	-6.8	-6.0	-1.7	-6.3	10.3	-0.2	-0.1	-0.3	-1.6	-0.2
Investment	-2.9	-1.7	-0.3	-0.9	2.1	-5.7	0.0	5.3	-0.3	-0.2
Exports	-12.5	-8.9	-4.4	2.1	-5.0	10.7	0.1	-4.4	2.2	-1.1
Imports	-13.1	-11.2	-3.8	-3.6	13.9	-3.6	0.0	-1.4	-0.8	-0.6
Real wages	-7.1	-4.6	0.9	-7.8	9.7	-2.1	-0.1	-1.3	0.8	0.0
Inflation	-15.1	-29.0	-0.4	10.9	-18.8	6.8	0.4	-0.2	2.6	-1.3
Dom. Prices	-12.5	-12.8	5.5	0.2	2.6	-6.9	0.0	0.4	-1.1	-0.7
Real ER	-9.4	-22.4	-10.7	2.5	-3.9	13.1	0.1	-3.1	2.6	-0.6

Table 3.10: Forecast error variance decomposition at different horizons under strict inflation targeting, in percentage point deviations from the current policy, adjusted for absence of monetary policy shocks

1 Quarter	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.9	-21.1	-14.1	0.3	5.2	2.0	5.7	0.4	0.4	0.1
Consumption	-3.0	-2.6	-2.1	-3.6	4.3	2.9	-0.1	0.5	-2.0	0.0
Investment	0.0	-0.4	-0.6	0.2	-0.6	0.8	0.0	0.1	0.1	0.0
Exports	-0.2	-18.0	-18.1	1.6	9.1	3.4	0.0	0.7	0.7	2.4
Imports	-4.0	-14.0	-11.7	-0.9	10.6	3.4	0.0	-1.2	-0.3	0.0
Real wages	-13.3	-11.9	-12.9	1.4	10.4	0.3	0.0	0.7	0.2	-0.3
Inflation	-15.3	-28.8	-28.9	3.0	16.4	7.4	0.0	0.9	1.6	-0.4
Dom. Prices	-13.3	-11.9	-12.9	1.4	10.4	0.3	0.0	0.7	0.2	-0.3
Real ER	-0.3	-83.2	-56.2	5.6	23.2	21.8	0.1	1.1	4.2	0.2
4 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-0.7	-7.6	-8.2	2.3	-0.2	1.7	0.9	2.5	1.2	-0.1
Consumption	-1.3	-6.3	-8.2	3.8	0.4	1.4	0.1	0.4	2.2	-0.1
Investment	-0.4	-0.2	-0.4	0.4	-1.5	1.3	0.0	0.2	0.2	-0.1
Exports	-3.5	-7.2	-10.2	0.9	6.5	0.5	0.0	0.8	0.1	1.4
Imports	-2.9	-13.0	-17.1	4.0	3.2	1.9	0.1	6.4	2.0	-0.3
Real wages	-3.5	-3.2	-4.4	0.5	2.2	1.0	0.0	0.5	0.2	0.0
Inflation	-14.7	-29.5	-32.0	3.0	17.4	9.4	0.1	1.0	1.9	-0.6
Dom. Prices	-12.3	-12.9	-14.4	1.5	10.5	1.6	0.0	0.7	0.4	-0.4
Real ER	-1.6	-35.0	-33.3	2.9	19.1	8.5	0.1	1.1	1.7	-0.1
8 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.5	-3.8	-4.1	1.9	-2.4	2.0	0.0	2.2	0.7	-0.2
Consumption	-3.9	-4.6	-6.0	6.6	-3.6	0.5	0.1	0.1	2.6	-0.3
Investment	-1.2	-0.2	-0.2	0.7	-2.9	1.4	0.0	1.0	0.2	-0.1
Exports	-9.5	-3.8	-4.9	0.5	3.3	-0.2	0.0	0.9	0.0	0.3
Imports	-8.7	-7.1	-9.1	4.6	-8.3	3.6	0.0	8.1	1.6	-0.6
Real wages	-5.3	-2.8	-3.7	4.2	-2.2	1.3	0.0	0.3	0.3	-0.1
Inflation	-14.8	-29.0	-31.4	2.9	17.0	9.4	0.1	1.0	1.9	-0.9
Dom. Prices	-12.1	-12.6	-14.2	1.5	10.4	1.7	0.0	0.8	0.5	-0.6
Real ER	-6.6	-24.1	-22.9	2.1	14.0	4.9	0.0	1.3	1.0	-0.3
∞	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-2.7	-3.8	-4.2	2.1	-2.6	1.2	0.0	3.3	0.4	-0.3
Consumption	-6.8	-6.0	-7.6	5.8	-1.1	0.7	0.1	0.9	1.7	-0.4
Investment	-2.9	-1.7	-2.1	1.1	-4.0	1.4	0.0	3.6	0.2	-0.3
Exports	-12.5	-8.9	-11.4	2.1	6.4	0.3	0.0	3.1	0.1	-0.6
Imports	-13.1	-11.2	-14.2	4.5	-2.4	3.5	0.0	8.5	1.1	-1.0
Real wages	-7.1	-4.6	-5.8	4.5	-1.1	1.2	0.0	1.1	0.3	-0.3
Inflation	-15.1	-29.0	-31.6	2.9	17.4	9.2	0.1	1.1	1.8	-1.0
Dom. Prices	-12.5	-12.8	-14.5	1.5	10.4	2.0	0.0	0.8	0.5	-0.7
Real ER	-9.4	-22.4	-23.1	2.9	13.3	3.4	0.0	3.4	0.7	-0.8

Table 3.11: Forecast error variance decomposition at different horizons under a fixed exchange rate, in percentage point deviations from the current policy, adjusted for absence of monetary policy shocks

1 Quarter	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.9	-21.1	-14.1	-6.3	49.9	-2.1	-18.0	-6.0	-3.4	0.0
Consumption	-3.0	-2.6	-2.1	-5.6	11.3	-0.5	-0.1	0.3	-3.3	0.0
Investment	0.0	-0.4	-0.6	0.1	3.1	0.0	0.0	-2.6	0.0	0.0
Exports	-0.2	-18.0	-18.1	-4.0	43.9	-14.3	-0.1	-1.0	-2.8	-3.8
Imports	-4.0	-14.0	-11.7	-3.4	33.7	-11.9	0.0	-5.3	-1.4	0.0
Real wages	-13.3	-11.9	-12.9	7.4	-26.7	25.5	0.2	1.7	5.0	-0.1
Inflation	-15.3	-28.8	-28.9	4.6	6.4	14.1	0.1	1.2	2.8	-0.3
Dom. Prices	-13.3	-11.9	-12.9	7.4	-26.7	25.5	0.2	1.7	5.0	-0.1
Real ER	-0.3	-83.2	-56.2	-3.2	78.2	-15.4	-0.1	-0.4	-2.9	-0.1

4 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-0.7	-7.6	-8.2	-4.8	27.1	-0.3	-3.7	-8.0	-2.0	-0.2
Consumption	-1.3	-6.3	-8.2	-7.2	26.4	-6.1	-0.1	-0.9	-3.8	-0.1
Investment	-0.4	-0.2	-0.4	0.3	2.5	0.3	0.0	-2.7	0.1	-0.1
Exports	-3.5	-7.2	-10.2	-4.0	29.3	-10.0	0.0	-1.6	-2.0	-1.5
Imports	-2.9	-13.0	-17.1	-2.8	32.5	-2.7	0.0	-8.6	-1.0	-0.4
Real wages	-3.5	-3.2	-4.4	-7.1	19.7	-5.7	-0.1	-0.5	-1.9	-0.1
Inflation	-14.7	-29.5	-32.0	4.2	9.0	15.2	0.1	1.2	2.9	-0.6
Dom. Prices	-12.3	-12.9	-14.4	6.9	-26.2	26.9	0.2	1.7	5.2	-0.3
Real ER	-1.6	-35.0	-33.3	-3.6	54.4	-13.8	-0.1	-0.9	-2.6	-0.2

8 Quarters	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-1.5	-3.8	-4.1	-1.9	12.7	-0.1	-1.2	-4.6	-0.6	-0.2
Consumption	-3.9	-4.6	-6.0	-3.0	16.2	-4.3	0.0	-1.2	-1.3	-0.3
Investment	-1.2	-0.2	-0.2	0.6	-0.3	0.7	0.0	-0.8	0.2	-0.1
Exports	-9.5	-3.8	-4.9	-3.3	17.2	-5.0	0.0	-2.1	-1.1	-0.6
Imports	-8.7	-7.1	-9.1	-0.2	13.7	-0.2	0.0	-3.7	0.0	-0.7
Real wages	-5.3	-2.8	-3.7	-3.8	13.3	-3.6	0.0	-0.8	-1.3	-0.1
Inflation	-14.8	-29.0	-31.4	4.0	9.3	14.8	0.1	1.2	2.8	-0.9
Dom. Prices	-12.1	-12.6	-14.2	6.7	-25.9	26.9	0.2	1.7	5.1	-0.4
Real ER	-6.6	-24.1	-22.9	-3.8	40.1	-9.1	0.0	-1.9	-1.9	-0.4

∞	η^m	η^{int}	η^{ω^*}	η^a	η^{po}	η^b	η^g	η^i	η^l	η^*
Real GDP	-2.7	-3.8	-4.2	0.1	4.7	-0.1	-0.4	0.1	0.0	-0.3
Consumption	-6.8	-6.0	-7.6	3.5	4.2	-0.7	0.0	0.0	1.0	-0.4
Investment	-2.9	-1.7	-2.1	1.2	-4.8	1.7	0.0	4.2	0.2	-0.3
Exports	-12.5	-8.9	-11.4	-0.1	13.7	-1.0	0.0	-0.2	-0.2	-0.9
Imports	-13.1	-11.2	-14.2	2.3	7.7	1.0	0.0	3.7	0.6	-1.1
Real wages	-7.1	-4.6	-5.8	2.1	4.3	-0.4	0.0	0.2	-0.1	-0.3
Inflation	-15.1	-29.0	-31.6	4.1	8.9	15.1	0.1	1.4	2.9	-0.9
Dom. Prices	-12.5	-12.8	-14.5	6.9	-26.7	27.6	0.2	1.9	5.2	-0.5
Real ER	-9.4	-22.4	-23.1	-3.1	37.4	-5.2	0.0	-3.9	-1.1	-0.9

Table 3.12: Forecast error variance decomposition at different horizons under ruble price of oil targeting, in percentage point deviations from the current policy, adjusted for absence of monetary policy shocks

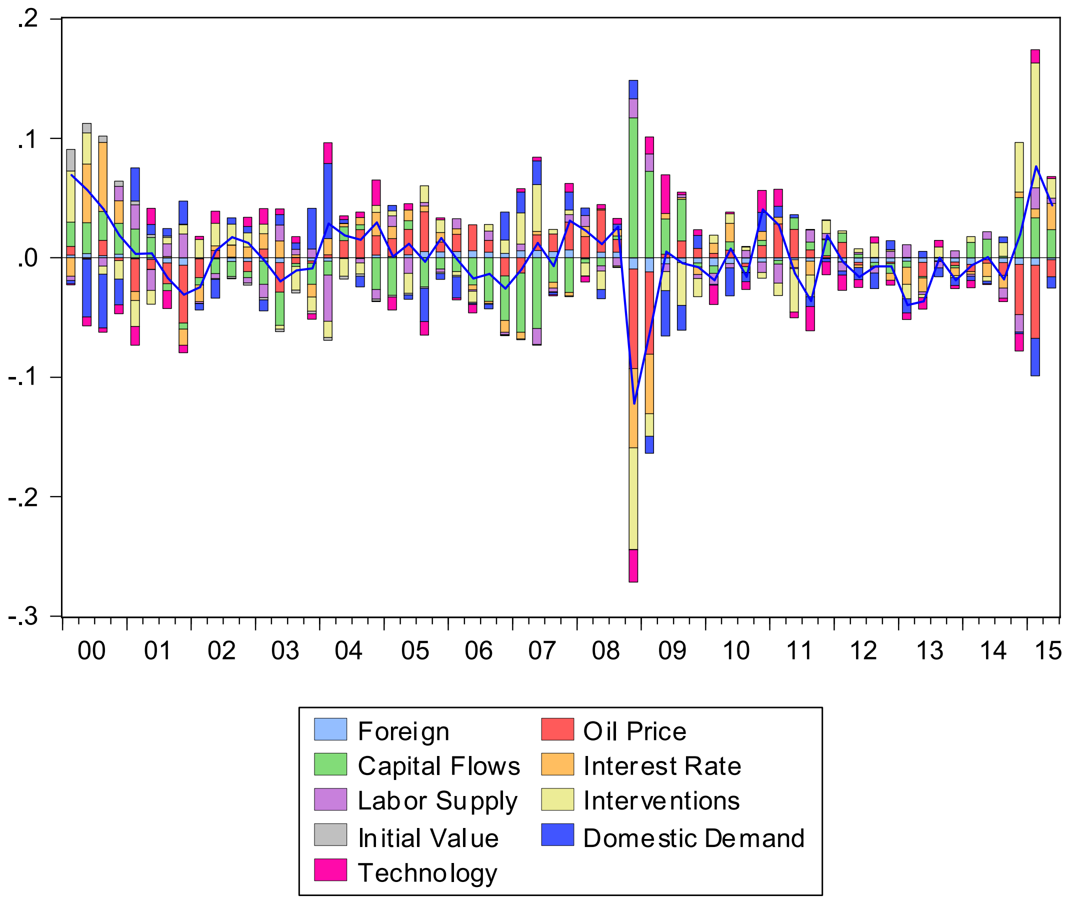

Figure 3.5: Historical decomposition of consumer price inflation (solid line)

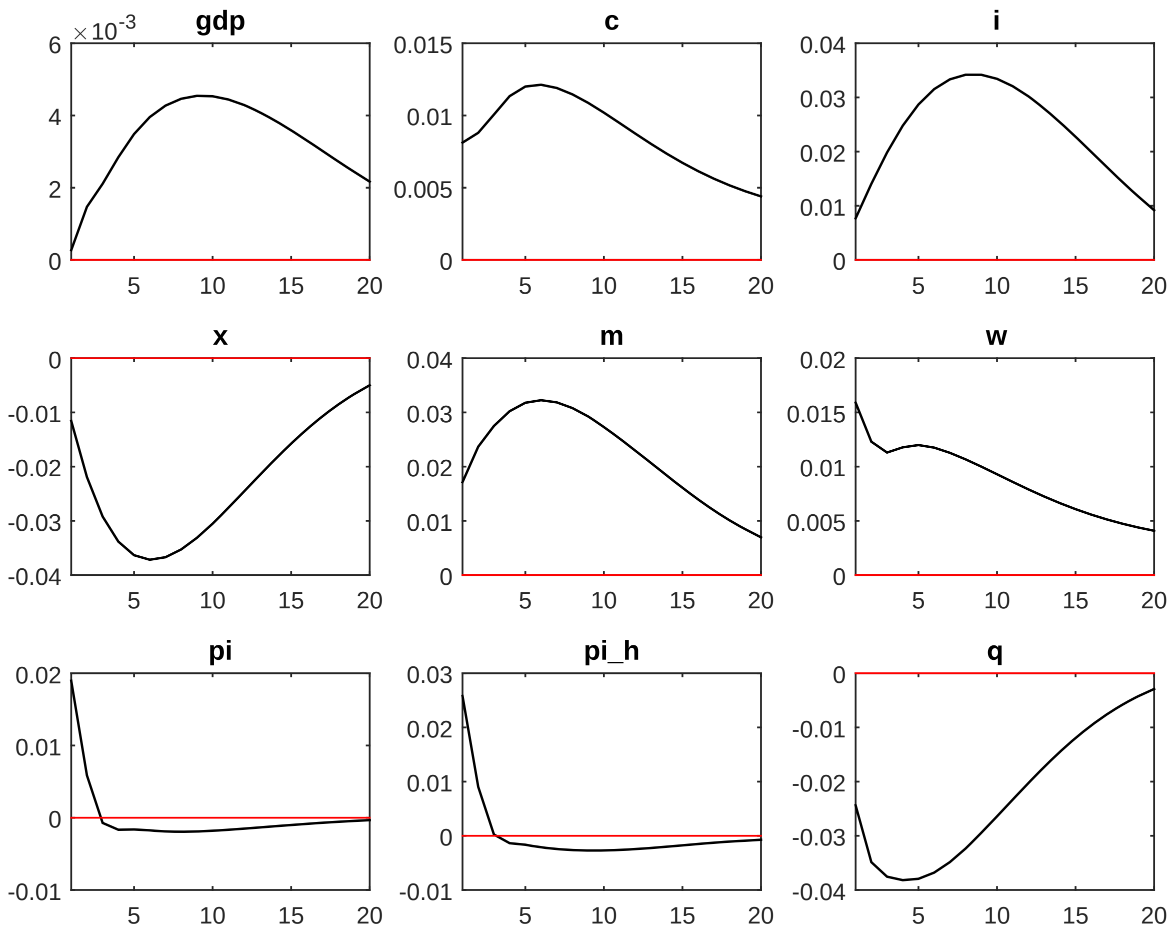

Figure 3.6: Impulse response functions following a 1 s.d. shock to the oil price

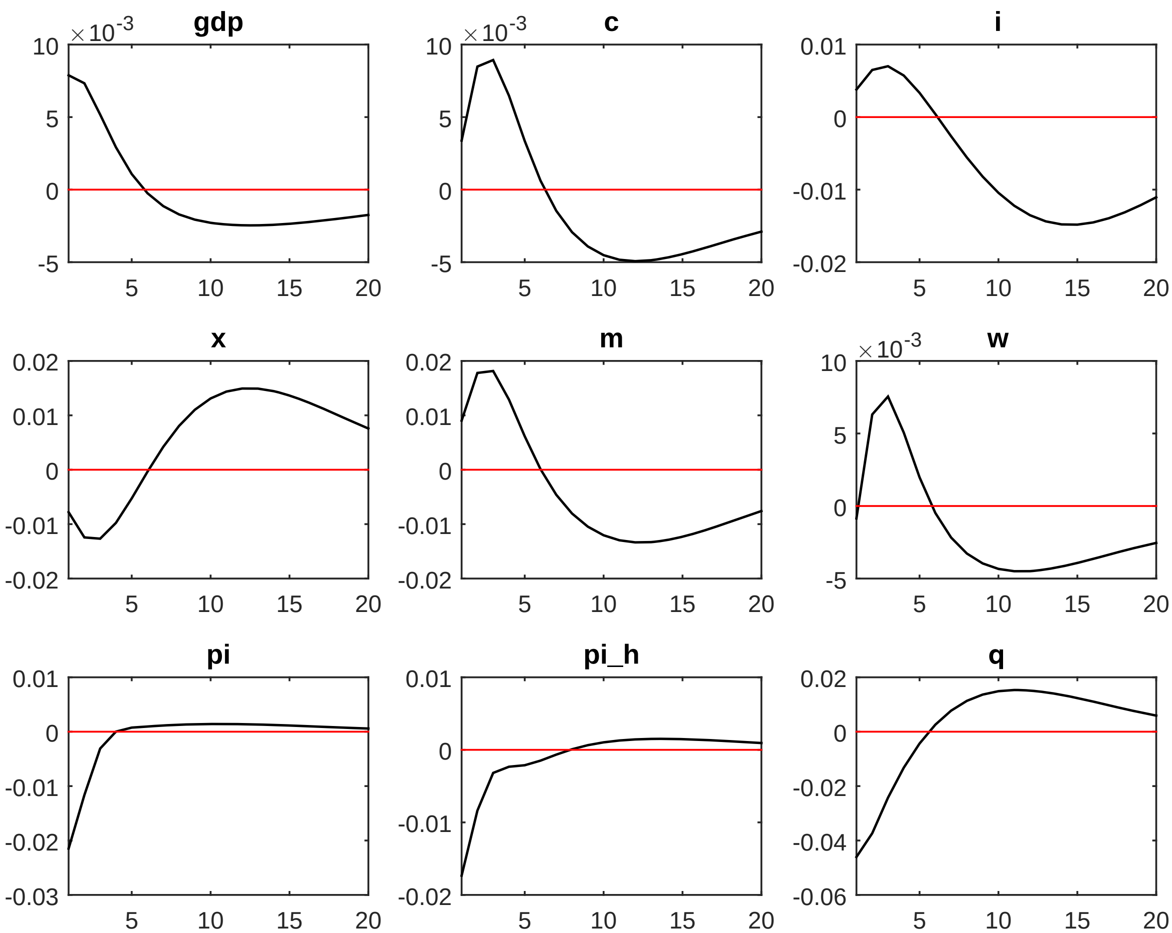

Figure 3.7: Impulse response functions following a 1 s.d. shock to capital flows

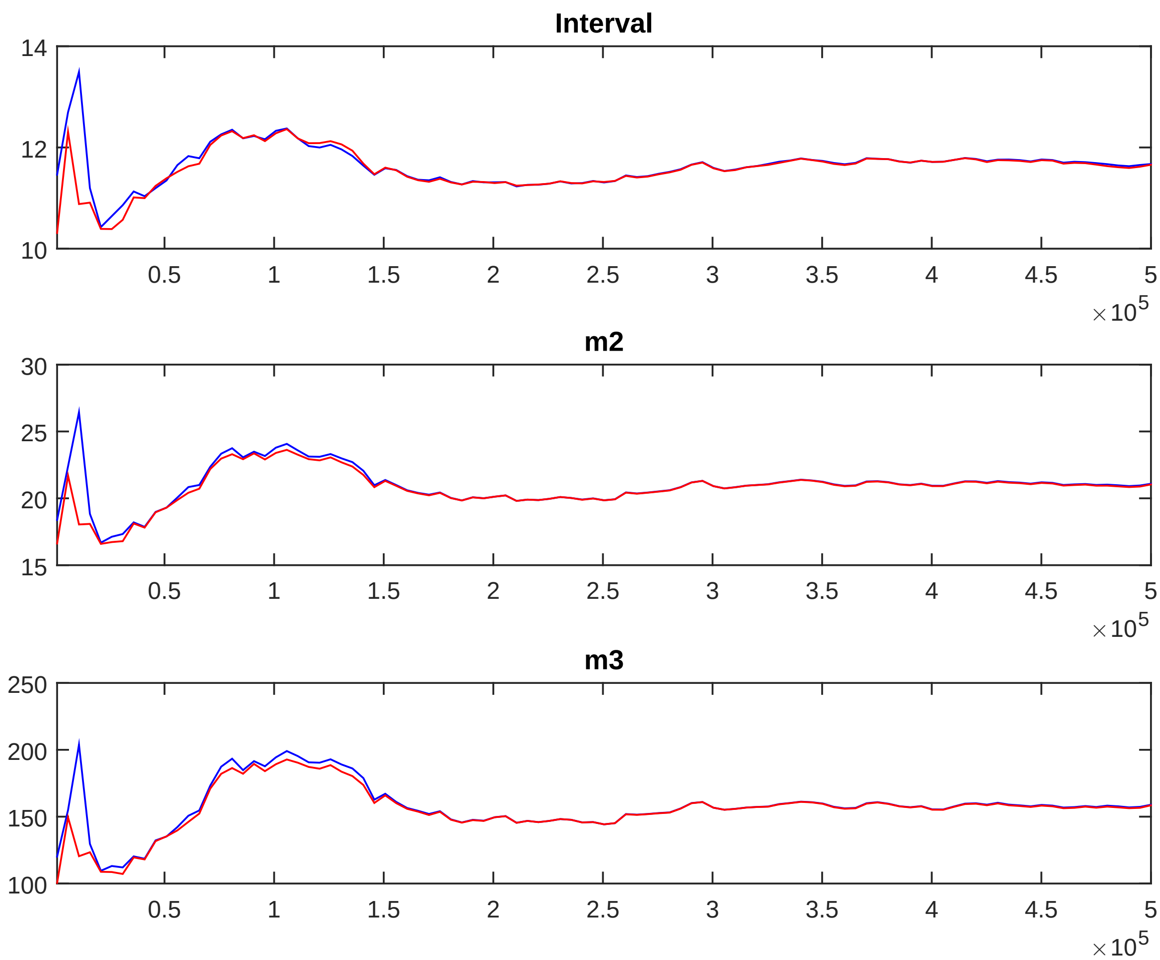

Figure 3.8: Multivariate convergence diagnostics for the Metropolis-Hastings

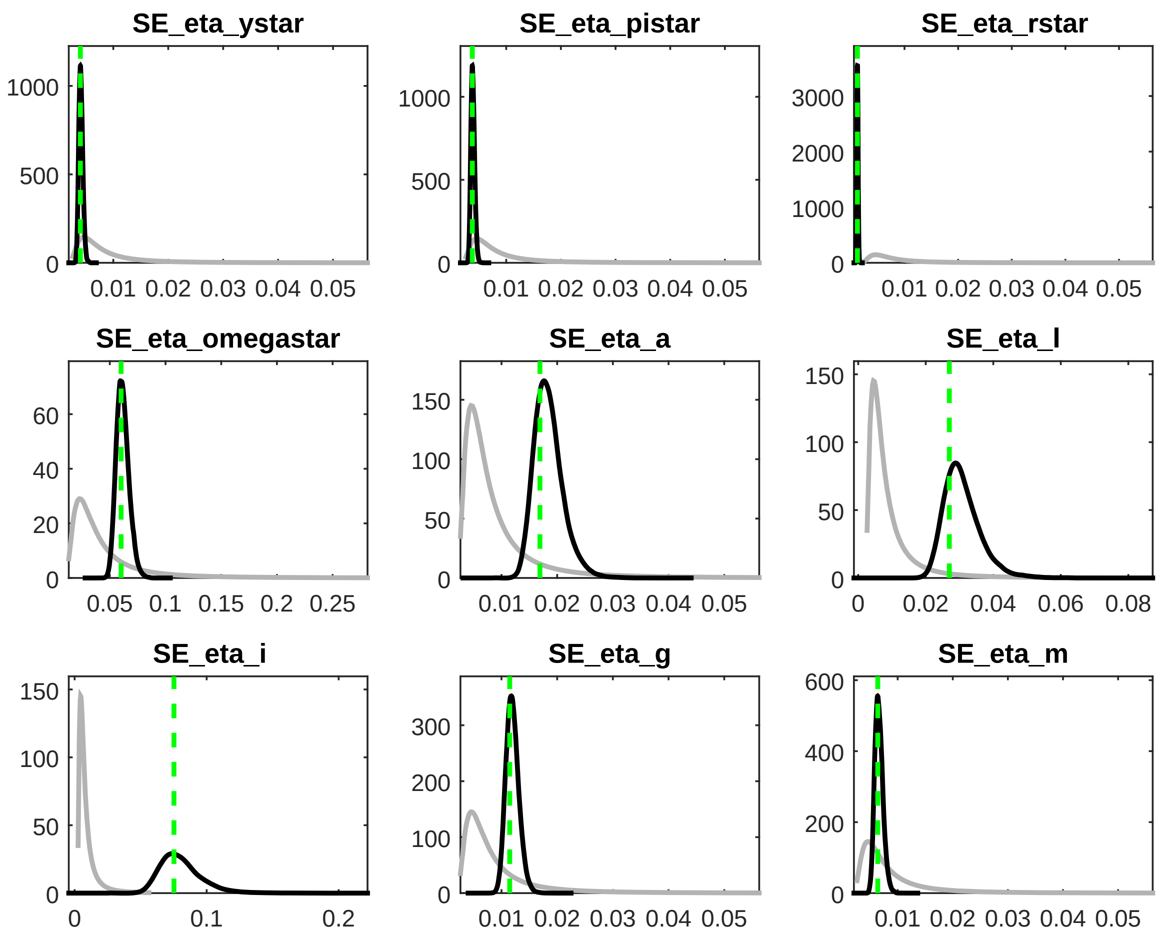

Figure 3.9: Priors and posteriors

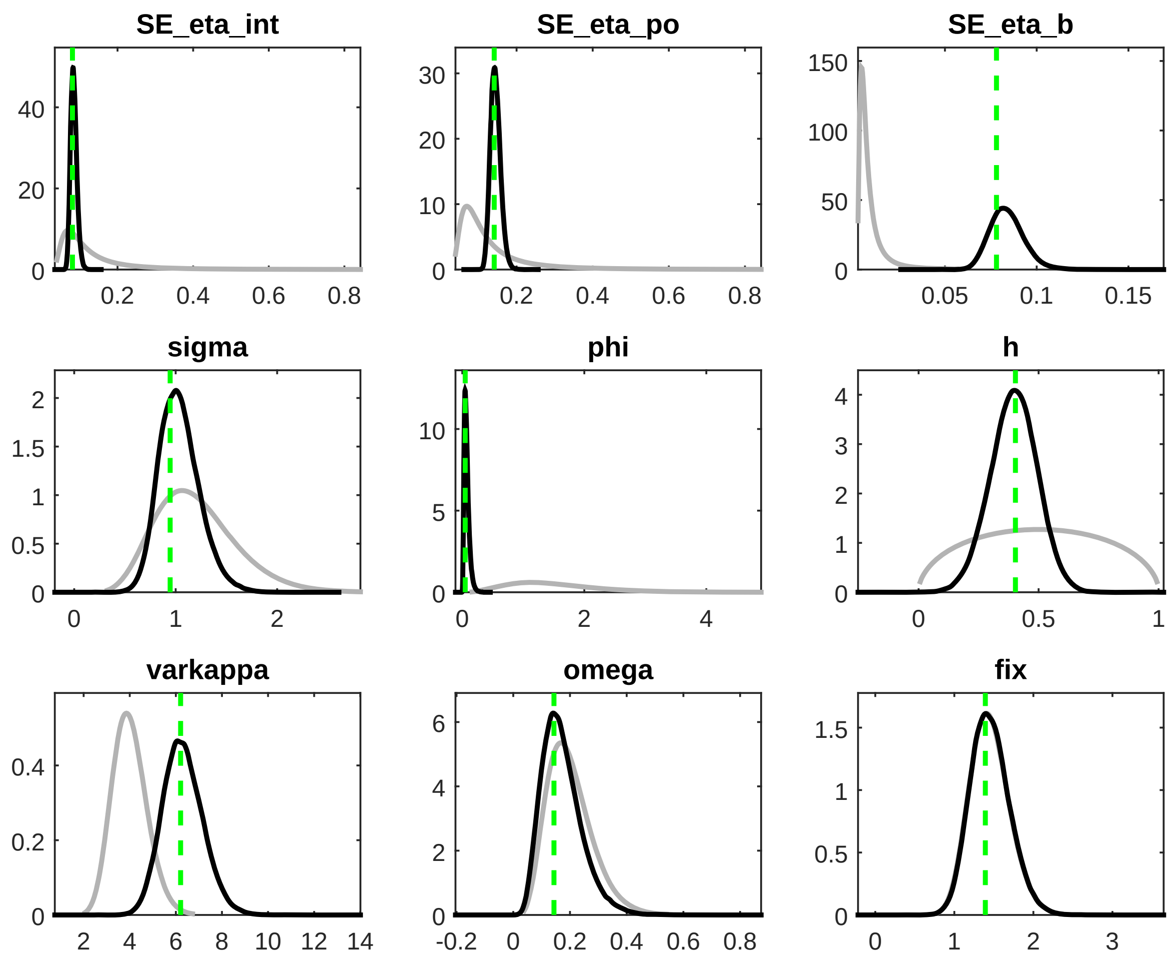

Figure 3.10: Priors and posteriors (cont.)

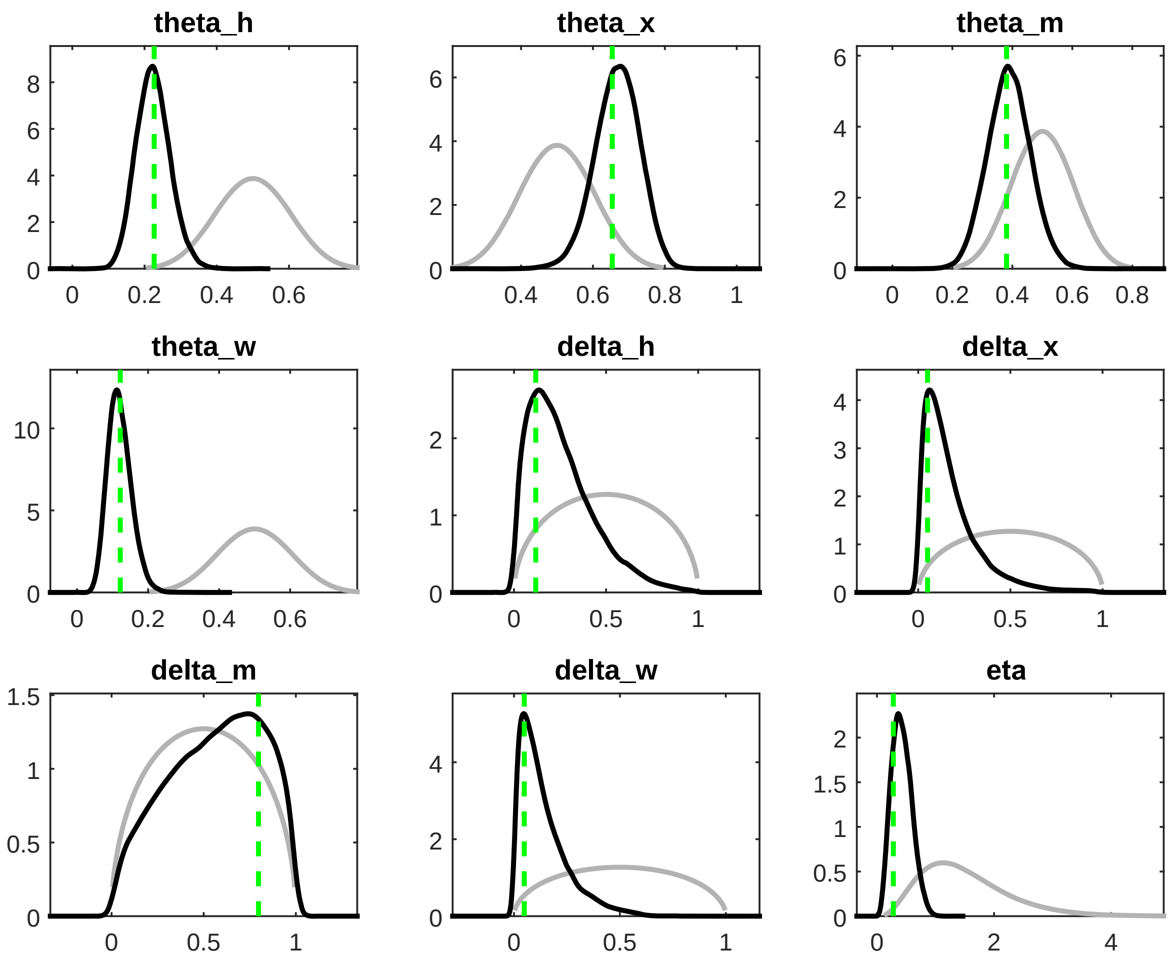

Figure 3.11: Priors and posteriors (cont.)

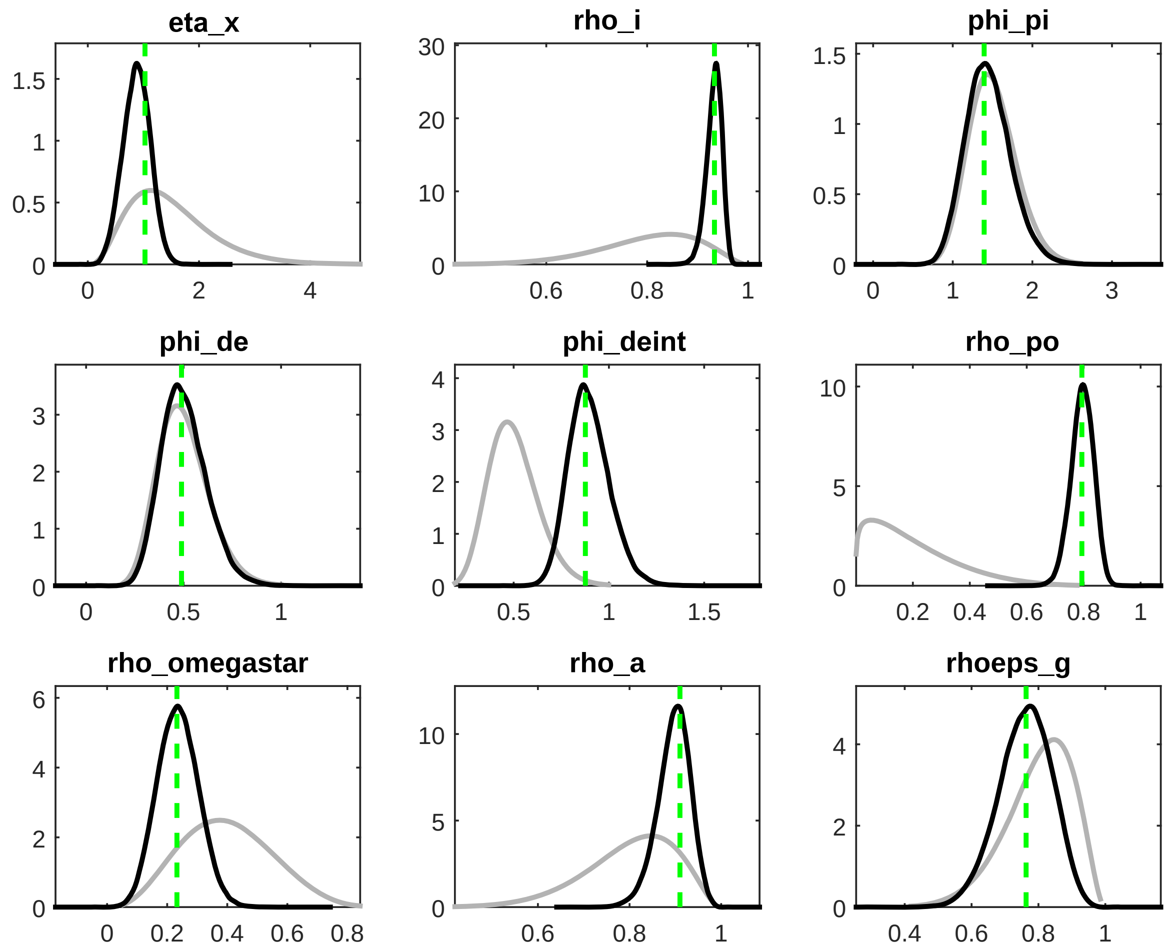

Figure 3.12: Priors and posteriors (cont.)

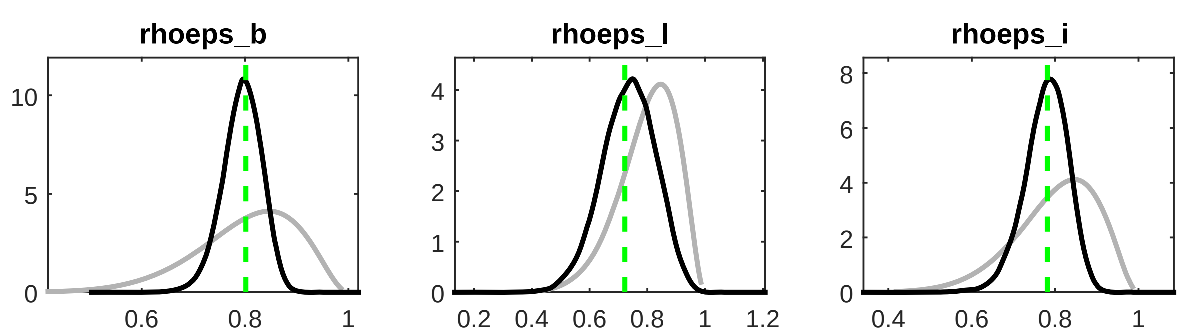

Figure 3.13: Priors and posteriors (cont.)

Chapter 4

The Effects of Fiscal Policy in an Estimated DSGE Model – The Case of the German Stimulus Packages during the Great Recession*

Abstract

This chapter analyzes the effects of the stimulus packages adopted by the German government during the Great Recession to mitigate the impact on the domestic economy. We employ a standard medium-scale dynamic stochastic general equilibrium (DSGE) model extended by non-optimizing households and a detailed fiscal sector. In particular, the dynamics of spending and revenue variables are modeled as feedback rules with respect to the cyclical component of output to account for their characteristics as automatic stabilizers. Based on the estimated rules, fiscal shocks are identified that do not fulfill the latter property and can thus be regarded as true impulses to the economy. According to the results, fiscal policy, in particular public consumption and transfers, stimulated the German economy during the recession, albeit only to a small extent and strongest when output was already expanding again. Neither stimulating nor contracting considerable effects have been estimated on the revenue side.

* This chapter is joint work with Oliver Holtemöller and Konstantin Kiesel.

4.1 Introduction

The recession of the years 2008 and 2009 has constituted the most severe one for Germany since the Second World War. In fact, the gross domestic product (GDP) dropped by 5.1 percent in 2009. The negative output gap increased to 5 percent representing a dimension that had been the last time measured during the 1973 oil crisis (Institut für Wirtschaftsforschung Halle and Kiel Economics, 2015). These severe developments increasingly shifted attention towards politicians, reflecting considerations of whether or not stabilizing policy measures might be eligible.

The crisis had originated in the financial sector. Consequently, financial support policies for individual banks and the total banking sector has been in the initial focus of action. In particular, liquidity injections, loan guarantees, capital injections, asset purchases and nationalizations were realized. Yet, in the light of the adverse situation in terms of real growth and growth perspectives, possible measures to dampen the effects on the real economy gained an increased attention.

Prior to the year 2009, fiscal stimulus packages have been regarded sceptically. Primarily potential implementation lags but also effectiveness lags often led to time-inconsistency problems and by that to a pro-cyclical impact. Moreover, the effects of fiscal stimuli on the business cycle has been viewed vague, both, theoretically and empirically. As a matter of fact, the primary role of business cycle stabilization has traditionally be assigned to monetary policy. Yet, approaching the zero lower bound for its respective policy rate, monetary policy increasingly faced constraints.[1] Moreover, the increased and persistent under-utilization of production capacities made potential adverse crowding-out effects through higher prices and interest rates, induced by the expansive fiscal policy, increasingly unlikely.

Accordingly, the German parliament enacted a series of measures to cut down the tax burden, to stabilize social security transfers and to spur investment, the German stimulus packages of the years 2009 and 2010. In fact, within these years additional discretionary fiscal policies in the amount of 104 billion euro have been instructed.

The recessionary period turned out to be over fast. Already in spring 2009 production growth turned positive again. The recovery that followed proceeded with a strong dynamic, such that already in early 2011 the output level before the crisis had been reached. Thus, the recovery was stronger then it had been expected in 2009.[2] Yet, to what degree the

[1] Unconventional monetary policies might provide a remedy in such a situation. However, it should be doubted whether they can substitute conventional policy one by one.

[2] See Projektgruppe Gemeinschaftsdiagnose (2009a,b) for macroeconomic forecast of that time.

experienced counter-movement in the afterward of the crisis can be attributed to the stimulus measures cannot be answered straightforwardly and deserves a deeper evaluation. This might be recommended on the one hand to critically analyze the timing, magnitude and design of the measures. On the the other hand, useful lessons for a similar situation in the future or other countries might be obtained.

In this work we evaluate the effectiveness of the fiscal stimulus packages in Germany. We specify and estimate a dynamic stochastic general equilibrium (DSGE) model to distinguish discretionary fiscal policy effects from those caused by automatic stabilizers and to evaluate the contributions of fiscal measures in comparison to other factors like preference shocks or technology shocks. We use the benchmark model of Smets and Wouters (2003) and extend it by non-optimizing households, the consideration of foreign trade, and, in particular, incorporate the fiscal authority in a rich way. Besides public debt we also account for three public income variables, consumption, capital and wage taxes, and three expenditure variables, namely public consumption, public investment and transfers. Afterwards, the model is estimated with Bayesian techniques for German quarterly data from 1999 till 2012.

The results reveal a positive albeit small contribution of discretionary fiscal policies on the cyclical output component during the Great Recession. At the maximum, the effect amounted to 0.8 percentage points. In the light of a decline in GDP of 5 percent, the fiscal measures hence helped to counteract the decline to some degree. However, compared to the impact of foreign shocks and private shocks, in particular to investment and preferences, the fiscal policy turned out to have been of minor importance. In addition, its effects on output are estimated to have been the largest, when the economy has been already growing again.

For the United Kingdom, Bhattarai and Trzeciakiewicz (2012) conduct a comparable analysis. A similar approach has also been used by Coenen et al. (2012). They evaluate fiscal policy in the euro area on aggregate during the Great Recession. However, we focus on the policy measures implemented in Germany and their effects on the domestic economy. Our work also borrows inspiration from Gali et al. (2007), who where the first that incorporated non-Ricardian ('rule-of-thumb') consumers that have no access to financial markets to intertemporary optimize their behavior into a standard New-Keynesian equilibrium model. The empirical evidence for the existence of such types of households has been provided by Campbell and Mankiw (1989) and Zeldes (1989), for example.[3] Some work has been devoted to the estimation of DSGE models featuring a detailed fiscal sector prior to the financial cri-

[3] Further evidence or explanations for the motives for a rule-of-thumb behavior are presented by Angeletos et al. (2001); Campbell and Mankiw (1990, 1991); Carroll (2001); Carroll and Kimball (2008); Coenen and Straub (2005).

sis (e.g. Ratto et al. (2009)). With the subsequent implementation of stimulus packages, the analyses of their effectiveness gained momentum. Among others, the domestic effects of fiscal stimulus packages have been evaluated by Coenen et al. (2012). They show the effects of fiscal policies according to seven structural DSGE models that are used by policy-making institutions. However, none of the seven models explicitly focuses on the German economy. Same holds true for the work of Cogan et al. (2010) who estimate a similar model for the United States. In this context, our contribution to the literature is twofold. First, we specify and estimate a rich, but still parsimonious open economy DSGE model. Second, we provide a detailed quantitative evaluation of the German fiscal stimulus packages based on our estimates.

The remainder of the chapter is structured as follows. Section 4.2 provides an overview of the fiscal stimulus packages. Section 4.3 lays out the details of our DSGE model with an emphasis on the fiscal sector. Section 4.4 elaborates on data and our estimation strategy. In section 4.5 we present the empirical results on the effectiveness of the fiscal stimulus packages. Afterwards, section 4.6 analyzes the results in terms of their sensitivity. Finally, section 4.7 concludes.

4.2 The German stimulus packages

The German stimulus measures were aimed to contribute support for three main areas. The first one was taxation, accordingly the measures were intended to cut down on the tax burden. The second were social security transfers reflecting the need to provide direct support for those households whose income and income perspectives were prone to strong decreases. The third was investment, with the intention to provide either increased public investment or to incentive households and entrepreneurs to not abandon planned investments.

In terms of implementation, the stimulus measures consisted of four packages that were successively enacted by the German parliament in October and November 2008 and in January and November 2009. Table 4.1 provides a detailed overview of each single measure arranged according to the four packages. Moreover, based on Institut für Wirtschaftsforschung Halle and Kiel Economics (2015) the volume of the measure (in billions euro) for each of the years from 2009 till 2012 is reported. The numbers presented state their nominal change to the year 2008, the last year before the start of the additional discretionary fiscal policies.

Modeling each single measure within a dynamic stochastic general equilibrium model would be very complex and hence likely unfeasible, nevertheless an analysis should be able to distinguish different fiscal policy instruments. Our model takes this into account by incor-

Fiscal Measure	Classification	2009	2010	2011	2012
Package I					
Increase children's allowance	Transfers/Labor Tax	2.3	2.2	2.2	2.2
Decrease unemployment insurance premium	Labor Tax	4.0	4.0	2.0	2.0
Improved deductibility of health insurance premia	Labor Tax		8.1	10.5	10.6
Package II					
Transport infrastructure investments	Gov. Consumption/Investment	1.0	1.0	-0.5	-0.5
Better financial deductibility for small- and medium-sized firms	Capital Tax	2.2	4.7	4.4	2.4
Tax exemption for new registered cars	Transfers	0.4	0.1		
Deductibility of craftsmen services	Consumption Tax	0.0	0.9	1.5	1.5
Program on building restoration	Gov. Investment	1.3	1.3	0.8	0.5
Package III					
Federal investments	Gov. Consumption/ Investment	2.0	2.0		
Federal and state Investments	Gov. Consumption/ Investment	6.7	6.7		
Revision of car taxes	Transfers	0.1	0.2	0.4	0.4
Car scrapping incentive	Transfers	4.1	0.9		
Decrease of income tax	Labor Tax/ Capital Tax	3.1	5.8	6.2	6.2
Children bonus	Transfers	1.5			
Increase of children's allowance for 6-13 years old	Transfers	0.2	0.3	0.3	0.3
Change on short-time work compensation	Labor Tax/ Capital Tax	1.1	1.2	0.8	0.3
Program on qualifications for rehiring temporary workers	Gov. Consumption/ Investment	0.2	0.2		
Expansion on further education of low-qualified workers	Gov. Consumption/ Investment	0.2	0.2	0.1	0.0
Additional resources for employment qualification measures	Gov. Consumption/ Investment	1.0	1.0		
Decrease of state health insurance premia	Labor Tax	3.1	6.3	0.5	
Program on innovations in mid-sized companies	Transfers	0.3	0.3	0.3	0.0
Fostering of promissing vehicle motors	Transfers	0.2	0.2	0.1	0.0
Package IV					
Increase of children's allowance	Transfers/ Labor Tax		4.3	4.5	4.7
Decrease on VAT of lodging	Consumption Tax		0.8	1.0	1.0
Change in heritage and energy laws	Transfers		0.3	0.5	0.4
Change on depreciation allowances	Capital Tax		0.7	2.2	2.8
Total		35.0	53.7	37.8	34.8

Table 4.1: Fiscal stimulus measures and their volumes in billions of euro. The numbers reflect the nominal change to the year 2008 and are based on Institut für Wirtschaftsforschung Halle and Kiel Economics (2015).

porating six fiscal instruments (see section 4.3). According to them, Table 4.1 also provides a classification of each single measure concerning its representation in our model. Consistent with our framework, these are public consumption and investment, taxing revenues on consumption, private capital and labor and, finally, transfer payments.

4.3 The model

The model consists of six types of agents and blocks: Ricardian households, non-Ricardian households, monopolistically competitive producers, a domestic fiscal authority, a monetary authority, and the aggregated foreign block. Further, the model features two types of frictions. Real frictions originate from habit formation and adjustments costs for investment and capital utilization. Nominal frictions are caused by rigidities of prices and wages and their partial indexation to their respective past inflation rate. In this section, we describe the behavior of the agents and their linkages and explain the potential channels of fiscal policies. Since the model largely builds on the work of Smets and Wouters (2003), we will only briefly address its main features and important relationships. The core full set of log-linearized equations is presented in Appendix D.

4.3.1 Households

The domestic economy is populated by a continuum of two different types of private households. A share of $(1-\mu)$ is assumed to have full access to financial markets and thus being able to optimize its behavior intertemporarily. In the remainder of the chapter we will refer to this kind of agents as Ricardian households or optimizers. The remaining households are assumed to be excluded from saving and borrowing. As a consequence, these types of households consume their entire disposable income each period. We will refer to them as non-Ricardian or rule-of-thumb households.

Ricardian households Optimizing households maximize their lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^r, L_t^r), \tag{4.1}$$

which is a function of consumption C_t^r and leisure $(1 - L_t^r)$

$$U(C_t^r, L_t^r) = \frac{\epsilon_t^p (C_t^r - hC_{t-1}^r)^{1-\sigma}}{1-\sigma} - \chi \frac{\epsilon_t^l}{1+\varphi} (L_t^r)^{1+\varphi}, \tag{4.2}$$

with h denoting the degree of habit persistence, L_t^r the hours worked and σ the intertemporal elasticity of substitution. The inverse Frisch elasticity φ measures the disutility from labor. χ is a scaling parameter to adjust the steady state of labor supply. ϵ^p and ϵ^l are shocks to consumption preferences and labor supply, respectively, that follow an AR(1) process in logs with i.i.d. normal shocks η^p and η^l. Households receive wage income W_t^r from labor, interest income on savings in domestic bonds B_t, income on real capital K_{t-1}^p rented to the production sector at the rental rate $r_{k,t}$, transfers TR_t from the government and profits Π_t from the firm sector. Income is spend on consumption C_t^r and investment I_t in private physical capital K_t^p. For the households budget constraint it thus follows:

$$\begin{aligned} P_t C_t^r \left(1+\tau_t^c\right) \quad & +P_t I_t + B_t + \Psi\left(\omega_t\right) K_{t-1}^p = \\ & R_{t-1} B_{t-1} + r_{k,t}\left(1-\tau_t^k\right)\omega_t K_{t-1}^p + \left(1-\tau_t^w\right) W_t^r L_t^r + \Pi_t + TR_t. \end{aligned} \tag{4.3}$$

where P_t is the price level, τ_t^c, τ_t^k and τ_t^w denote taxes on consumption, capital and labor, R_t is the one-period gross nominal return on domestic government bonds, W_t is the nominal wage, ω_t specifies the degree of capital utilization, with $\Psi\left(\omega_t\right))$ being the cost associated with its variations. Following Christiano et al. (2001), we assume that in steady state the capital utilization rate is $\bar{\omega} = 1$ and $\Psi\left(\left(\bar{\omega}\right)\right) = 0$. The accumulation of private physical capital is determined according to the following law of motion:

$$K_t^p = \left(1-\delta\right) K_{t-1}^p + \left(1 - S\left(\cdot\right)\right) I_t, \tag{4.4}$$

where $S\left(\cdot\right)$ is the investment adjustment cost function:

$$S\left(\frac{\epsilon_t^i I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{\epsilon_t^i I_t}{I_{t-1}} - 1\right)^2. \tag{4.5}$$

The function reflects the assumption that adjusting the capital stock to its optimal level is costly.[4] κ captures the investment adjustment cost, η_t^i, in turn, denotes the corresponding shock to these adjustment costs.

Ricardian households maximize their utility subject to their budget constraint and the capital accumulation function with respect to consumption, labor, bond holdings, investment, the size of next period's capital stock and its rate of utilization.[5]

[4] The function $S\left(\cdot\right)$ is restricted to satisfy the following properties: $S(1) = S'(1) = 0$ and $S''(1) > 0$. Given the solution procedure, no other features of the $S\left(\cdot\right)$ function need to be specified for our analysis (Christiano et al., 2001).

[5] The respective first order conditions are presented in Appendix D.

Rule-of-thumb households Non-optimizing households are assumed to have no access to financial markets, so that they do not own assets, and do not have liabilities or conduct investments. Accordingly, their entire current income, that is composed of net labor income and transfer receipts from the government, is spent for consumption purposes:

$$(1+\tau_t^c)C_t^n = (1-\tau_t^w)L_t^n W_t^n + TR_t. \tag{4.6}$$

Household aggregation Since rule-of-thumb households constitute a share μ of total households, aggregate private consumption is given by:

$$C_t = \mu C_t^n + (1-\mu)C_t^r.$$

Wage setting Households offer differentiated labor services and thus act as monopolistically competitive wage setters in the labor market. Each period a random fraction of $1-\theta^w$ households is 'allowed' to optimize its wage, whereas the remaining fraction adjusts its wage according to a simple indexation rule, with the degree of indexation being measured by $\omega^w \in [0,1]$. An employment agency bundles the differentiated labor services according to a Dixit-Stiglitz-type function and sells the composite labor index to the production sector at the aggregate wage index W_t. Optimizing household will set their wage to $\tilde{W}_t$ taking into account the demand for their individual labor service and the probability of future adjustments. For the dynamics of the aggregate wage index it then follows:

$$W_t = \left[(1-\theta^w)\left(\tilde{W}_t\right)^{-\frac{1}{\lambda^w}} + \theta^w\left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\omega^w} W_{t-1}\right)^{-\frac{1}{\lambda^w}}\right]^{-\lambda^w}, \tag{4.7}$$

with $\lambda_W \in [0,\infty]$ being the net wage markup as a result of the households market power.

We assume, that non-Ricardian households will set their wage to the average wage of optimizing households and that, hence, the demand for labor services of non-optimizers is the same as for the aggregate of Ricardian households. Consequently, labor hours and wages will be identical for both types of consumers, so that $L_t = L_t^r = L_t^n$ and $W_t = W_t^r = W_t^n$.

4.3.2 Firms

Production The economy consists of a continuum of firms $x \in [0,1]$ of which each one produces a differentiated good according to a Cobb-Douglas technology:

$$Y_t(x) = Z_t L_t(x)^{1-\alpha}(\omega_t K^p_{t-1}(x))^{\alpha}(K^g_{t-1}(x))^{\zeta} - \Xi, \tag{4.8}$$

where Z_t represents an shock to total factor productivity that follows a first-order autoregressive process (in logs): $z_t = \rho_z z_{t-1} + \eta^z_t$, where $\eta^z_t \sim (0, \sigma^2_z)$. K^g_{t-1} is the public capital stock, whereas Ξ measures the fixed cost of production.[6] The firm takes factor prices as given and minimizes the costs for a particular level of output subject to the production technology. Labor demand is identical for all firms and given by:

$$L_t = \frac{1-\alpha}{\alpha} K^p_{t-1} \frac{r_{k_t}}{W_t}, \tag{4.9}$$

whereas marginal costs are:

$$MC_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^{\alpha} Z_t^{-1} K_{t-1}^{-\zeta}(x)\, W_t^{1-\alpha} r^{\alpha}_{k,t}. \tag{4.10}$$

Resulting profits of the firms are assumed to be passed on to the optimizing households as dividends.

Price setting Firms set their prices in a Calvo (1983) fashion. Each period a random fraction $(1-\theta_p) \in [0,1]$ of firms adjust their prices to the optimal level $\tilde{P}_t$. Firms that are not able to adjust, index their prices to past inflation, with the degree of indexation given by $\omega_P \in [0,1]$. Moreover, monopolistic competition leads to a gross mark-up $\lambda_p \in [1,\infty]$ of the optimal price over marginal cost for each producer x. Individual producers' goods are aggregated to a final goods index by competitive retail firms according to a Dixit-Stiglitz function. For the total price index it follows from the demand for individual goods in the final goods index, the price setting behavior of adjusters and non-adjusters:

$$P_t = \left[(1-\theta_p)\tilde{P}_t^{\frac{1}{1-\lambda_p}} + \theta_p \left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\omega_p} P_{t-1}\right)^{\frac{1}{1-\lambda_p}}\right]^{1-\lambda_p}. \tag{4.11}$$

[6] The assumption of increasing returns to scale with respect to public capital can be found in Baxter and King (1993), Glomm and Ravikumar (1997), Turnovsky (2004), and Leeper et al. (2010). The condition, $\alpha + \zeta < 1$, is necessary to ensure a stable balanced growth path (see Turnovsky (2004)).

4.3.3 Fiscal authority

The fiscal authority is characterized by eight variables: public consumption G_t^c, public investment G_t^i, taxing rates on consumption τ_t^c, private capital τ_t^k and labor τ_t^W, transfer payments TR_t and the stock of public bonds issued B_t. Analogously to private capital, public capital is accumulated according to the following law of motion:

$$K_t^g = (1 - \delta^g)K_{t-1}^g + G_t^i. \tag{4.12}$$

The government faces a real flow budget constraint that balances its expenses on interest and debt payments, transfers as well as consumption and investment to the its revenues from taxes on consumption, wages and private capital and cash return from bonds issued in the current period. For the government budget constraint it thus follows:

$$B_{t-1}R_{t-1} + TR_t + G_t^c + G_t^i = \tau_t^c C_t + \tau_t^k r_t^k \omega_t K_{t-1}^p + \tau_t^w W_t L_t + B_t. \tag{4.13}$$

We broadly follow Leeper et al. (2010) in specifying spending and revenue rules for the fiscal sector. Government expenditures on consumption and investment are assumed to respond in a countercyclical manner to deviations of output and debt from their respective steady states. To account for possible delays in the implementation of spending plans in reaction to economic developments, we consider the respective lagged values. Due to a large proportion of unemployment benefits in government transfers that are not subject to such delays we specify the rule for this kind of fiscal expenditure in reaction to the contemporaneous cyclical component of hours worked. For the spending rule it follows (in log-linear approximation):

$$g_t^c = \rho_{gc,y} y_{t-1} + \rho_{c,b} b_{t-1} + \epsilon_t^{gc} \tag{4.14}$$

$$g_t^i = \rho_{gi,y} y_{t-1} + \rho_{i,b} b_{t-1} + \epsilon_t^{gi} \tag{4.15}$$

$$tr_t = \rho_{tr,l} l_t + \rho_{tr,b} b_{t-1} + \epsilon_t^{tr}, \tag{4.16}$$

where $\epsilon_t^{gc} = \rho_{gc}\, \epsilon_{t-1}^{gc} + \eta_t^{gc}$, $\epsilon_t^{gi} = \rho_{gi}\, \epsilon_{t-1}^{gi} + \eta_t^{gi}$ and $\epsilon_t^{tr} = \rho_{tr}\, \epsilon_{t-1}^{tr} + \eta_t^{tr}$, with η_t^{gc}, η_t^{gi} and η_t^{tr} being i.i.d. shocks with zero mean and variances $\sigma_{\eta gc}^2$, $\sigma_{\eta gi}^2$ and $\sigma_{\eta tr}^2$.

On the revenue side, consumption, labor and capital tax rates can also be assumed to adjust in a way to stabilize the economy. Thus, feedback rules can be specified to react to deviations of the output from its trend. Similarly, if debt is above its steady state value the government is assumed to act in terms of a debt brake rule that forces it to increase taxes. Vice versa, in case of a debt increase below trend, the government will make use of the leeway in the next period by lowering taxes.[7] In log-linear approximation it follows that:

$$\tau_t^c = \rho_{\tau c,y} y_{t-1} + \rho_{\tau c,b} b_{t-1} + \epsilon_t^{\tau c} \tag{4.17}$$

$$\tau_t^w = \rho_{\tau w,y} y_{t-1} + \rho_{\tau w,b} b_{t-1} + \epsilon_t^{\tau w} \tag{4.18}$$

$$\tau_t^k = \rho_{\tau k,y} y_{t-1} + \rho_{\tau k,b} b_{t-1} + \epsilon_t^{\tau k}, \tag{4.19}$$

where $\epsilon_t^{\tau c} = \rho_{\tau c}\epsilon_{t-1}^{\tau c} + \eta_t^{\tau c}$, $\epsilon_t^{\tau w} = \rho_{\tau w}\epsilon_{t-1}^{\tau w} + \eta_t^{\tau w}$ and $\epsilon_t^{\tau k} = \rho_{\tau k}\epsilon_{t-1}^{\tau k} + \eta_t^{\tau k}$, with $\eta_t^{\tau k}$, $\eta_t^{\tau k}$ and $\eta_t^{\tau k}$ being i.i.d. shocks with zero mean and variances $\sigma_{\eta\tau c}^2$, $\sigma_{\eta\tau w}^2$ and $\sigma_{\eta\tau k}^2$.

4.3.4 Monetary policy

The monetary authority acts according to a feedback rule in the spirit of Taylor (1993). In addition, we allow for an interest rate smoothing as in (Clarida et al., 2000). Being a member of a monetary union, the interest rate in Germany equals the one set by policy makers considering the whole euro area. Accordingly, the Taylor rule specifies the interest rate as a reaction function of GDP–weighted average inflation rates and output gaps of Germany and the rest of the euro area (REA):

$$r_t = \rho_r r_{t-1} + (1-\rho_r)(\rho_\pi \pi_t^{REA} + \rho_y y_t^{REA}) + \eta_t^r, \tag{4.20}$$

where $\eta_t^r \sim (0, \sigma_{\eta r}^2)$ captures non-systematic deviations of the interest rate from the monetary policy rule. Both REA variables are modeled as VAR(2) processes in logs, considering the area-wide interest rate as an endogenous component:

$$\begin{bmatrix} y_t^{REA} \\ \pi_t^{REA} \end{bmatrix} = \rho_1 \begin{bmatrix} y_{t-1}^{REA} \\ \pi_{t-1}^{REA} \\ R_{t-1} \end{bmatrix} + \rho_2 \begin{bmatrix} y_{t-2}^{REA} \\ \pi_{t-2}^{REA} \\ R_{t-2} \end{bmatrix} + \begin{bmatrix} \eta_t^{y^{REA}} \\ \eta_t^{\pi^{REA}} \end{bmatrix}, \tag{4.21}$$

where ρ_1 and ρ_2 are 2×3 matrices of coefficients and $\eta_t^{y^{REA}}$ and $\eta_t^{\pi^{REA}}$ are i.i.d. normal shocks with zero mean and variances $\sigma_{\eta y^{REA}}^2$ and $\sigma_{\eta\pi^{REA}}^2$.

[7] From a technical perspective, the formulation of fiscal rules with a consideration of public debt is a method to ensure stationarity of the latter.

4.3.5 Goods market clearing

Goods market clearing requires the output produced net of utilization costs to equal the demand for private as well as public consumption and investment. To match the model equations with the observed data series and to account for the importance of trade for the German economy, we introduce the trade balance TB_t as an exogenous component. It then follows:

$$Y_t = C_t + I_t + G^c t + G^i_t + TB_t + \Psi(\omega_t) K^p_{t-1}, \tag{4.22}$$

with the dynamics of the trade balance given by an AR(1) process in logs:

$$tb_t = \rho_{tb}\, tb_{t-1} + \eta^{tb}_t, \tag{4.23}$$

with η^{tb}_t being an i.i.d. normal error term with zero mean and variance $\sigma^2_{\eta tb}$. We abstract from modeling any further channels for international spillovers, as government expenditures can almost entirely be assumed to be directed to spending on domestic goods. In addition, since we use data on all remaining GDP components for estimation, the trade balance is well identified in the process to allow us to draw conclusions about the effects of foreign trade on domestic output.

4.3.6 Channels of fiscal policy

The policymakers have six discretionary policy measures at their disposal that can be grouped in two categories. Government consumption, government investment and government transfers constitute expenditure policy measures. Changes to the tax rates on wage income, capital and consumption represent revenue-based policy measures. Changes of these measures will eventually affect the consumption and investment behavior of Ricardian and non-Ricardian households and the output of the economy. In general, there is a wide variety of channels on which the policy measures work their way through the economy. We distinguish between direct and indirect effects, whereby indirect effects can be further subdivided along the channels of interest rates, labor and wage.

Direct effects occur via the households' budgets. That is, a decrease of the consumption tax rate will lead to a higher immediate real income for both types of households. In turn, a decrease of the wage tax rate will especially affect non–Ricardian households for whom the wage income is of particular importance. The latter holds also true for transfer payments. If the government increases them, it will directly affect the households' budgets.

Indirect effects via interest rates are based on several factors that condition each other consecutively. On impact, a fiscal expenditure impulse will lead to a direct increase of output. As this additional demand has to be served by means of an increased production, but labor constitutes the only input factor that can react immediately, working hours rise. This makes capital the relatively scarce factor. Hence, the interest rate on capital rises, too. As the capital rental rate is a crucial part of a firms cost, marginal costs rise. Obviously, an increase of the price level in general occurs as firms transform the higher costs into higher goods prices. However, this will force monetary policy to react, as it is assumed that central bankers respond to inflation and output developments. Since both rise, interest rates increase immediately. Accordingly, Ricardian households will, ceteris paribus, decrease consumption, that is a crowding-out of private spending occurs. In addition, a decrease in the shadow price of capital is expected to lead to a drop in private investment spending.

Another channel acts through indirect effects via labor. In this case, the non-Ricardian households are the crucial agents. As before, a fiscal expenditure impulse induces a rise in output and capital reacts staggered, since investments take a period to increase the capital stock. Thus, working hours need to increase. Non-Ricardians will hence consume more, as they have a higher disposable labor income available.

Non-Ricardians are also crucial for explaining the effects of a fiscal impulse on the revenue side. That is, if the fiscal authority decides to lower consumption or labor tax rates an indirect effect via wages will occur. However, the direction of the effect on consumption is ex ante inconclusive. On the one hand, the reduction of taxes causes the marginal rate of substitution between labor and consumption to fall. Hence, wages are expected to fall as well. On the other hand, the reduced taxes allow to spend more of the households' income. Estimation is thus necessary to determine which of the both effects predominates.

4.4 Estimation

4.4.1 Data and priors

For the Bayesian estimation of the model 15 quarterly time series are used. These include domestic series for GDP, private and government consumption, private and government investment, government transfers, effective tax rates for consumption, labor and capital income, hours, wages, and CPI inflation. In addition, we use the euro area short-term interest rate, as well as series for GDP and inflation in the rest of the euro area. The latter two aggregates are constructed as evolving GDP weighted averages of the respective EMU members' time series. German GDP aggregates as well as hours and wages are divided by the

Private capital depreciation rate	δ	0.0250
Public capital depreciation rate	δ_G	0.0250
Share of capital in production function	α	0.3200
Share of public capital in production function	ζ	0.1000
Steady-state wage markup parameter	λ_w	0.1500
Steady-state labor tax rate	τ_w	0.4428
Steady-state consumption tax rate	τ_c	0.2136
Steady-state capital tax rate	τ_k	0.1806
Steady-state private consumption to GDP ratio	C/Y	0.5788
Steady-state private investment to GDP ratio	I/Y	0.1686
Steady-state public consumption to GDP ratio	G^C/Y	0.1899
Steady-state public investment to GDP ratio	G^I/Y	0.0165
Steady-state transfer payments to GDP ratio	TR/Y	0.2081
Steady-state public debt to GDP ratio	B/Y	2.5868
Discount factor	β	0.9980
Steady-state return on capital	r^K	0.0336

Table 4.2: Calibrated model parameters and steady-state values

population time series to obtain per capita values and by that to remove the common trend in these series. Effective tax rates are calculated following Mendoza et al. (1994). To account correctly for the structural break resulting from the introduction of the single European monetary policy, all series start from 1999 and range till 2012. The cyclical components of the variables used for estimation are extracted by means of the Hodrick-Prescott filter. The choice of this particular method instead of the widely used linear detrending is primarily motivated by the increase in turnover tax rates at the beginning of 2007. A consideration of deviations from the sample mean as the true cyclical values would result in an overvaluation of the tax rate before the increase and, respectively, an undervaluation thereafter. For reasons of consistency, the same method is applied to all series.

Values for structural parameters and those that are difficult to estimate are set according to the respective sample means or to values widely used in the relevant literature (Table 4.2). In particular, the depreciation rates for private and public capital are both set to $\delta = \delta^g = 0.025$, implying an annual depreciation of 10 percent, and the net wage markup parameter to $\lambda^w = 0.15$. The discount factor β is set to 0.998, to match the inverse of the average quarterly gross real interest rate over the sample period. In a similar way, the steady-state tax rates and the ratios of the GDP aggregates and public debt to output are set at their average trend ratios. Based on these numbers, the steady-state transfers to GDP ratio is obtained from the government budget constraint and the private capital to GDP ratio from its law of motion.

The steady-state return on private capital r^K reflects the values for the steady-state capital tax rate, the private depreciation rate, and the discount factor β. The shares of private and public capital in the production function is set to 0.32 and 0.10, to match the steady-state share of labor income to GDP to its sample average of 68 percent. Finally, marginal cost is calibrated to 0.8, implying a steady-state price markup over production costs of 25 percent. The remaining steady-state values are pinned down by estimated parameters. Choices for prior distributions of the estimated parameters and shocks reflect standard approaches in the literature and are presented in Table 4.3.

4.4.2 Posterior means

Results for the posterior distribution of the estimated parameters and shocks variances are documented in Table 4.3. Most of the values fall within the expected range. Concerning the relevant parameters for the assessment of fiscal policy, the estimation reveals a share of non-Ricardian households of slightly more than one fifth, which is in line with the results of other studies for advanced countries (Bhattarai and Trzeciakiewicz, 2012; Iwata, 2009).

Posterior means for the reaction coefficients in the fiscal policy rules reveal strong considerations of the stance of the business cycle for four out of six instruments. In particular, all spending variables react heavily countercyclical. The dependence of the extent of public outlays on the output gap (or cyclical employment) is strongest for transfers, followed by investment. Both of these findings reflect economic intuition. Transfers can be seen as a prime example for automatic stabilizers, consisting to a large share of unemployment payments, whereas public investment spending is commonly regarded as a measure to stimulate economic activity in the context of fiscal stimulus packages, respectively. Government consumption, on the other hand, consists to a larger extent of outlays that are independent of the business cycle. Even though many of the measures usually agreed upon to stimulate the economy fall into this spending category, their relative share in total government consumption is small. The smaller reaction coefficient to the output gap in the respective spending rule captures that accordingly. On the revenue side, capital taxes are estimated to react strongly to movements in the cyclical component of the output and thus to be set in a countercyclical manner. The same applies to the consumption tax rate, however to a far smaller extent and statistically not different from zero, indicating that these are rather changed non-systematically. The effective labor tax rate, on the contrary, are estimated to increase in an economic downturns and to decrease in upturns. This finding reflects the regularity that low-paid jobs that are taxed at a lower rate are more sensitive to the eco-

			Prior		Posterior		
Parameter		Distr.	Mean	S.d.	Mean	Conf.	Interval
Habit persistence	h	beta	0.50	0.10	0.3797	0.2447	0.5099
Share of non-Ricardians	μ	beta	0.30	0.10	0.2289	0.1092	0.3417
Consumption utility	σ	norm	1.00	0.38	1.2353	0.8154	1.6560
Labor utility	φ	norm	2.00	0.50	2.3399	1.6243	3.0636
Indexation prices	ω^p	beta	0.40	0.15	0.2702	0.1014	0.4382
Calvo parameter prices	θ^p	beta	0.50	0.10	0.8216	0.7796	0.8608
Indexation wages	ω^w	beta	0.40	0.15	0.3133	0.1061	0.5108
Calvo wages	θ^w	beta	0.50	0.10	0.2747	0.1846	0.3623
Fixed cost	ξ	norm	1.40	0.10	1.6076	1.4758	1.7343
Investment adj. cost	$\varkappa$	norm	4.00	1.50	3.5645	1.7432	5.3426
Capitl utilization adj.	κ	norm	0.40	0.10	0.4332	0.2721	0.5881
Interest rate smoothing	ρ_r	beta	0.80	0.10	0.8342	0.7757	0.8963
Taylor coeff. inflation	ρ_π	norm	1.50	0.10	1.4596	1.2964	1.6233
Taylor coeff. output	ρ_y	norm	0.10	0.05	0.0921	0.0214	0.1614
AR(1) trade balance	ρ_{tb}	beta	0.80	0.10	0.7859	0.6559	0.9207
AR(1) gov. consumption	ρ_{gc}	beta	0.80	0.10	0.7270	0.6004	0.8537
AR(1) gov. investment	ρ_{gi}	beta	0.80	0.10	0.5838	0.4357	0.7304
AR(1) gov. transfers	ρ_{tr}	beta	0.80	0.10	0.7199	0.6053	0.8383
AR(1) cons. tax rule	$\rho_{\tau c}$	beta	0.80	0.10	0.5533	0.3896	0.7206
AR(1) labor tax rule	$\rho_{\tau w}$	beta	0.80	0.10	0.6704	0.5127	0.8341
AR(1) capital tax rule	$\rho_{\tau k}$	beta	0.80	0.10	0.6700	0.5292	0.8178
Gov. Cons. Output Reac.	$\rho_{gc,y}$	norm	0.00	0.50	0.2016	0.0463	0.3510
Gov. Cons. Debt Reac.	$\rho_{gc,b}$	norm	0.00	0.50	0.0160	-0.1149	0.1452
Gov. Inv. Output Reac.	$\rho_{gi,y}$	norm	0.00	0.50	0.4643	0.1452	0.7804
Gov. Inv. Debt Reac.	$\rho_{gi,b}$	norm	0.00	0.50	0.1188	-0.0476	0.2800
Gov. Tran. Labor Reac.	$\rho_{tr,l}$	norm	0.00	0.50	0.5341	0.2972	0.7698
Gov. Tran. Debt Reac.	$\rho_{tr,b}$	norm	0.00	0.50	-0.0362	-0.1553	0.0865
Cons. Tax Output Reac.	$\rho_{\tau c,y}$	norm	0.00	0.50	0.0709	-0.0335	0.1710
Cons. Tax Debt Reac.	$\rho_{\tau c,b}$	norm	0.00	0.50	0.0225	-0.1020	0.1434
Labor Tax Output Reac.	$\rho_{\tau w,y}$	norm	0.00	0.50	-0.0434	-0.0939	0.0075
Labor Tax Debt Reac.	$\rho_{\tau w,b}$	norm	0.00	0.50	-0.0362	-0.1166	0.0445
Capital Tax Output Reac.	$\rho_{\tau k,y}$	norm	0.00	0.50	0.3393	0.1795	0.4965
Capitl Tax Debt Reac.	$\rho_{\tau k,b}$	norm	0.00	0.50	0.0899	-0.0533	0.2366
AR(1) technology shock	ρ_z	beta	0.80	0.10	0.6966	0.5980	0.7971
AR(1) investment shock	$\rho\varepsilon_i$	beta	0.80	0.10	0.7691	0.5995	0.9503
AR(1) preference shock	$\rho\varepsilon_p$	beta	0.80	0.10	0.5835	0.4405	0.7284
AR(1) labor supply shock	$\rho\varepsilon_l$	beta	0.80	0.10	0.5713	0.3963	0.7498
S.d. gov. consump. shock	η^{gc}	invg	0.01	2.00	0.0083	0.0070	0.0096
S.d. gov. investm. shock	η^{gi}	invg	0.01	2.00	0.0553	0.0464	0.0637
S.d. gov. transf. shock	η^{tr}	invg	0.01	2.00	0.0104	0.0088	0.0120
S.d. cons. tax shock	$\eta^{\tau c}$	invg	0.01	2.00	0.0060	0.0050	0.0070
S.d. labor tax shock	$\eta^{\tau w}$	invg	0.01	2.00	0.0027	0.0023	0.0031
S.d. capital tax shock	$\eta^{\tau k}$	invg	0.01	2.00	0.0095	0.0079	0.0110
S.d. trade balance shock	η^{tb}	invg	0.01	2.00	0.0348	0.0295	0.0401
S.d. technology shock	η^{z}	invg	0.01	2.00	0.0051	0.0042	0.0059
S.d. labor supply shock	η^{l}	invg	0.01	2.00	0.0474	0.0239	0.0711
S.d. investment shock	η^{i}	invg	0.01	2.00	0.0086	0.0023	0.0173
S.d. preference shock	η^{p}	invg	0.01	2.00	0.0200	0.0137	0.0260
S.d. monet. policy shock	η^{r}	invg	0.01	2.00	0.0013	0.0011	0.0015
S.d. capital price shock	η^{q}	invg	0.01	2.00	0.1147	0.0568	0.1706
S.d. cost push shock	η^{cp}	invg	0.01	2.00	0.0866	0.0477	0.1255
S.d. foreign output shock	η^{yrea}	invg	0.01	2.00	0.0053	0.0045	0.0061
S.d. foreign infl. shock	$\eta^{\pi rea}$	invg	0.01	2.00	0.0025	0.0021	0.0028

Table 4.3: Priors and posteriors of model parameters and standard deviations of shocks

nomic cycle. With a relatively higher share of slashed jobs in the lower tax rate segment, the effective tax rate, which reflects the average rate, rises consequently.

All of the six fiscal variables react hardly to movements in the government debt level. Its consideration in the fiscal rules, however, primarily stems from the need to render the variable stationary. An economic interpretation of the size of the respective reaction parameters is thus rather subdued. Finally, all of the six fiscal variables exhibit a medium high degree of smoothing, with the respective AR(1) parameters ranging from 0.55 to 0.73.

4.4.3 Shock identification

Based on the estimates of the rules' parameters, smoothed shocks for all six fiscal variables are obtained and depicted in Figure 4.1. For the three spending variables, stimulating measures can be identified during the time of the stimulus packages. Measures that can be attributed to public consumption and transfers exceeded levels expected by the estimated long-run rule by an average of around one per cent per quarter. Stimulus efforts in the area of government investment turn out to be markedly higher. They exceed the levels implied by the respective rule by more than five percent in two of the eight quarters under consideration. On the revenue side, expansive measures can be identified for the labor tax rate, including social security contributions, however to a far lower extent. The effective consumption tax rate proved to be neither expansive nor restrictive in the time period under consideration. The capital tax rate, on the other hand, deviated from its implied long-run rule value in an expansive way in only one quarter, even though substantially.

4.4.4 A note on the size of the shocks in comparison to the original fiscal measures

Within our model the size of the stimulating measures is identified through the shocks. More generally, the size of the measures result as an outcome of 'bringing the model to the data', whereby the model incorporates assumptions about the behavior of fiscal policy makers and the latter is quantified by estimating the model. Having identified the discretionary fiscal policy shocks, a comparison to the officially announced size of the measures might be of interest and hence advisable.

To do so we compare the year-to-year change of the size of the official measures from Table 4.1 with the yearly average of the shocks shown in Figure 4.1. Additionally, we add the size of the measures induced by implied automatic stabilizers and induced by the inertiaassumption that underlies the models' fiscal reaction function. This can be demonstrated exemplary for public consumption:

$$c_t^G = \underbrace{\rho_{cy} y_{t-1} + \rho_{cd} d_{t-1} + \rho^{c^G} \epsilon_{t-1}^{c^G}}_{\text{Automatic Stabilizers}} + \underbrace{\eta_t^{c^G}}_{\text{Discretionary Fiscal Policy}} . \quad (4.24)$$

As can be seen from the individual graphs in Figure 4.4, for several instruments and time periods the sum of the models' shocks plus the automatic stabilizers reaches a size that is similar to the magnitude of the announced fiscal measures. However, there are also several observations when this is not the case.

Yet, this should not come as a surprise, as at least three reasons make an expected parity not to occur necessarily. The first one concerns the preciseness of the official numbers in comparison with when they take their full effect. Accordingly, the announced numbers are precise at the moment when they are announced but might turn out different as time moves on. Especially implementation lags might cause delays. The second one is the unknown counterfactual. The corresponding spending and revenue patterns that would have occurred if fiscal stimulus packages had not been implemented are ex-post unknown. Discretionary public investments plans for several years ahead, for example, do not necessarily reflect the fact that some of the projects starting at a later point of time would have been financed by other resources in the future anyway. Moreover, the increased willingness to spend money, that is a decisive feature of stimulus packages might incentivize client politics. If that would be the case, then projects would be financed that had been for a long time on a political agenda but did so far not find enough support, e.g. due to political or economic reasons. A third issue concerns the nature of the discretionary policy measures itself. By definition, they should be discretionary, however some of the measures comprise a time horizon that is much longer. The increase of the children allowance, for example, is intended to remain in force for a longer period of time. Hence comparing its size to the year 2008 yields an increase for all the years thereafter. Yet from a growth and general equilibrium perspective, its effect on the economy should only be temporary.

Compared to the official numbers of the packages announced, our model addresses the above mentioned issues by yielding a quantification of the underlying deviation from a general equilibrium growth path. Thus, DSGE modeling enables the identification of possible counterfactual spending and revenue patterns. Moreover, by using data from the national account systems the problem of implementation lags is ruled out, as these numbers reflect ex-post the actual spending at and for a specific point of time. Moreover, our set up allows to identify temporary from permanent policy measures.

Summing up, the following point has hence to be stressed. The model provides an alternative view to identify the size and effectiveness of the announced fiscal discretionary policy measures. A direct comparison of identified shocks and the official announced numbers is prone to misunderstandings and hence should be dealt with care.

4.5 Effects of the stimulus packages

Based on the estimation in the previous section and the derived smoothed shocks, the effects of discretionary fiscal policy measures on output can be analyzed. Figure 4.2 shows the historical decomposition of the German output gap from 1999 till 2012. The 16 model shocks are grouped into four broad categories: foreign shocks, consisting of the trade balance shock and deviations of the rest of euro area GDP and inflation from their respective long run dynamics, the monetary policy shock, capturing non-systematic deviations of the policy rate from the estimated Taylor rule, fiscal shocks, containing the six fiscal rule disturbances, as well as domestic shocks, that include the remaining six shocks in the model. Over the whole time period considered, fiscal shocks had only marginal effects on output. In none of the 56 quarters, fiscal shocks had an impact on the output by more than one percentage point (Figure 4.3). Far greater had been the influence of foreign shocks which does not appear surprisingly given the openness of the Germany economy. Estimation results suggest that the big drop in output at the beginning of 2009 can primarily be attributed to negative foreign shocks, in particular a negative trade balance disturbance, reflecting a lower world demand for German products and thus shrinking exports. On the other hand, however, the recovery in global trade that already started at the end of 2009 proved to be the major stimulus for the German economy well through the year 2010. The shocks with the largest influence on the output, though, are estimated to have been of domestic origin. Whereas over the whole sample considered shocks to the shadow rate of investment affected the output strongest, adverse preference shocks had an equally large negative impact during the most recent recession.

The effects of monetary policy shocks are observed as well. Reflecting the assumed behavior of business cycle smoothing as laid down in the Taylor rule, monetary policy in the euro area has decelerated output growth in Germany during boom times and supported the economy during troughs. This does not entirely hold true for the period of the Great Recession. However, in the year 2010 the impact of monetary policy has been of near equal size as the one of fiscal policies.

Among the fiscal variables, the largest positive impact can be attributed to government consumption and thus stimulating effects of measures such as the creation of positions of job center facilitators, concessions of infrastructure investments, and renovations of school buildings. In the first three quarters of 2009, public consumption expenditures positively influenced the output gap by around 0.3 percentage points on average. Even though the identified positive shocks to government investment have been much greater, its low share in the German GDP resulted in a much lower and almost negligible impact in the particular quarters. By contrast, the historical decomposition of the output gap suggests that discretionary public investment spending had curbed domestic production in all but two quarters between 2009 and 2010, primarily due to negative shocks. Consequently, based on the estimated spending rule, public investment spending appears to have been too low. Government transfers stimulated the German economy from the middle of 2009 well until mid-year 2011, with the largest impacts of around 0.4 percentage points in the first three quarters of 2010, pointing at a positive effect of the car scrapping incentive and several kinds of allowances. On the revenue side, positive and negative effects of the three model tax rates are neutralized over the quarters of interest. Whereas negative shocks to the consumption and capital tax rates are estimated to have contributed to the recovery from 2010 on, the positive impact of the labor tax rate on output from the second quarter of 2010 suggests that reduced contributions to the social security insurance to have eventually stimulated the economy.

In total, the fiscal policy instruments under consideration had an average positive impact on German output of 0.4 percentage points per quarter in the years 2009 and 2010. However, policy measures are not estimated to have prevented a larger downturn or to have offset the negative effects of other disturbances during that time. In the first two quarters of 2009 fiscal policy is even estimated to have had a negative effect in the sense that it should have been more expansive given the economic environment. The largest positive effects on output have been estimated starting from the beginning of 2010. Fiscal policy has been stimulating the economy considerably throughout that year, when GDP was growing again at an average of 1.1 percent. Thus, the overall positive effects can be to large extent considered as procyclical, even though the output gap has still been negative at that time.

4.6 Sensitivity analysis

Having presented the results of the baseline model specification, this section turns to sensitivity analysis. More precisely, we examine to what degree the results hinge on the model setup.

In particular, we test whether the assumption of non-Ricardian households in the economy is crucial for stimulus measures estimated to have been effective. Moreover, alternative fiscal reaction functions and their impact on the effectiveness of the fiscal policy measures will be provided. It turns out that the findings of the baseline setup are not sensitive with respect to these changes in the model specification.

The first alternative model specification ('No RoT consumers') excludes rule-of-thumb consumers from the economy by setting ($\mu = 0$) prior to the estimation. From a theoretical perspective the expectation would hence be that policy measures have a lower impact compared to the baseline setup. This would be due to the fact that the direct effects are lower, as non-Ricardian households, which spent all income immediately, are now 'substituted' by Ricardian households that are instead able to smooth consumption. Accordingly, these households would take intertemporal substitution into account and therefore spent only a partial amount of the additional income they receive directly or indirectly through fiscal stimulus packages. Indeed, the estimation of this model specification confirms these considerations. Figure 4.5 shows that in most of the quarters of interest, the contribution of discretionary fiscal policy to the output gap is lower when excluding rule-of-thumb consumers. However, the difference is small and does not exceed 0.1 percentage points in all but one quarters. From a theoretical view not surprisingly, the difference between both specifications is biggest for the quarters in which the smoothed shocks to government transfers were the largest.

The other alternative model specifications concern the design of fiscal reaction functions, as this might have a significant influence on the results. In the baseline specification we assume that fiscal variables react to movements in the output gap, labor hours and the debt level, however, the authority could also consider other/further variables. Based on the particular setup and the economic environment, different revenue and expenditure levels might be considered as rule-based, thus leading to a different identification of shocks considered as discretionary policy.

For our alternative fiscal rules we build on the work by Kliem and Kriwoluzky (2014) (KK) by adding hours worked, l_t, to the labor tax rule and private investment, i_t, to the capital tax rule ('KK rules'):

$$\tau_t^w = \rho_{\tau w,y} y_t + \rho_{\tau w,b} b_{t-1} + \rho_{\tau w,l} l_t + \epsilon_t^{\tau w} \tag{4.25}$$

$$\tau_t^k = \rho_{\tau k,y} y_t + \rho_{\tau k,b} b_{t-1} + \rho_{\tau k,i} i_t + \epsilon_t^{\tau k} \tag{4.26}$$

As a further alternative, we extend the rules proposed by KK, by adding hours worked also to the government consumption rule as well as private investment to the public investment reaction function ('Extended KK rules'):

$$g_t^c = -\rho_{gc,y} y_{t-1} - \rho_{gc,b} b_{t-1} - \rho_{gc,l} l_t + \epsilon_t^{gc} \tag{4.27}$$

$$g_t^i = -\rho_{gi,y} y_{t-1} - \rho_{gi,b} b_{t-1} - \rho_{gi,i} i_t + \epsilon_t^{gi} \tag{4.28}$$

Figure 4.5 compares the results under these different model specifications. The first set of alternative fiscal rules ('KK rules') does not significantly alter the results. However, when also introducing hours worked and private investment into the spending rules ('Extended KK rules'), the extent to which fiscal policy has affected output during 2009 and 2010 is comparable to the specification with no rule-of-thumb consumers. This result stems from a higher proportion of government consumption and transfers being attributed to rule-based spending, when taking into account the reduction in hours worked. The share of discretionary expenditures identified through the respective smoothed shocks is hence lower for both variables causing the overall stimulus and by that its effects being smaller. As for the specification with no non-Ricardian households, however, the difference between the effects in the alternative and the baseline scenario is small, not exceeding 0.1 percentage points per quarter. The overall assessment of the effectiveness of fiscal policy remains unaffected by the estimation of different model specifications. Whereas its effects are estimated to have been negative during the quarters when the overall economy was contracting, fiscal policy stimulated domestic production at a time when it has been already expanding again.

Generally, the results of our baseline scenario thus can be regarded as being not sensitive with respect to the inclusion of non-Ricardian households and alternative fiscal rule specifications.

4.7 Conclusion

Similar to most other developed countries, the German government adopted several policy measures to mitigiate the impact of the Great Recession on the domestic economy. In this work, we assess their actual effectiveness in the framework of an estimated DSGE model. To account for the cyclical behavior of fiscal variables, in particular the characteristics of automatic stabilizers, we specify six equations for the dynamics of spending and revenue variables as feedback rules. Based on them and the respective variables' time series, we identify the actual fiscal shocks, in contrast to total changes in spending and revenues variables that are also due to automatic stabilization properties of the latter. In doing so, we also correctly account for their unexpected dynamics component that enables us to better assess their impacts. Our estimates hint at overall positive effects of fiscal policy on German output in the years 2009 and 2010, most of which can be attributed to government transfers and consumption. Their total impact is, however, moderate compared to other domestic and foreign shocks. Moreover, fiscal policy is estimated to have been to restrictive at the time when it was supposed to support the shrinking domestic production while the economy has been stimulated the most when it started to expand again, although with the output gap being still negative. The estimated results do not appear be sensitive to the model specification, as alternative setups point largely to the same effects.

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Appendix D: Model equations and steady-state relationships

First order conditions

FOC of optimizing households wrt. consumption:

$$\epsilon_t^p \left(C_t^r - hC_{t-1}^r\right)^{-\sigma} = (1+\tau_t^c)\,\lambda_t \tag{4.29}$$

FOC of optimizing households wrt. investment:

$$\begin{aligned} Q_t S'\left(\tfrac{\epsilon_t^i I_t}{I_{t-1}}\right)\tfrac{\epsilon_t^i I_t}{I_{t-1}} - \quad & \beta E_t Q_{+1}\tfrac{\lambda_{t+1}}{\lambda_t} S'\left(\tfrac{\epsilon_{t+1}^i I_{t+1}}{I_t}\right)\left(\tfrac{\epsilon_{t+1}^i I_{t+1}}{I_t}\right)\tfrac{I_{t+1}}{I_t} + 1 = \\ & Q_t\left(1 - S\left(\tfrac{\epsilon_t^i I_t}{I_{t-1}}\right)\right) \end{aligned} \tag{4.30}$$

FOC of optimizing households wrt. labor

$$\epsilon_t^p \epsilon_t^l L_t^{\varphi} = -(1-\tau_t^w)\lambda_t \frac{W_t}{P_t} \tag{4.31}$$

FOC of optimizing households wrt. bond holdings:

$$\lambda_t P_t = \lambda_{t+1} P_{t+1} \beta R_t \tag{4.32}$$

FOC of optimizing households wrt. next period's capital stock:

$$Q_t = \beta \frac{\lambda_{t+1}}{\lambda_t}\left(r_{t+1}^K + Q_{t+1}\left(1-\delta\right)\right) \tag{4.33}$$

FOC of optimizing households wrt. the capital utilization rate:

$$\Psi'\left(\omega_t\right) = \left(1-\tau_t^k\right) r_t^k \tag{4.34}$$

Log linearized equations

Households

Consumption Euler equation of optimizing households:

$$\begin{aligned} c_t^r = \quad & \tfrac{1}{1+h} c_{t+1}^r + \tfrac{h}{1+h} c_{t-1}^r + \tfrac{1-h}{\sigma(1+h)} \tfrac{\bar{\tau}^c}{1+\bar{\tau}^c}\left(\tau_{t+1}^c - \tau_t^c\right) - \tfrac{1-h}{\sigma(1+h)}\left(r_t - \pi_{t+1}\right) \\ & + \tfrac{1-h}{\sigma(1+h)}\left(\epsilon_t^p - \epsilon_{t+1}^p\right) \end{aligned} \tag{4.35}$$

Consumption of rule-of-thumb households:

$$c_t^n = \frac{1}{1+\bar{\tau}^c}\left(\left(\frac{\bar{W}\bar{L}}{\bar{Y}}\left((1-\bar{\tau}^w)(w_t+l_t)-\bar{\tau}^w\tau_t^w\right)+\frac{\bar{TR}}{\bar{Y}}\,tr_t\right)\frac{1}{\frac{\bar{C}^n}{\bar{Y}}}-\bar{\tau}^c\,\tau_t^c\right) \tag{4.36}$$

Aggregate consumption:

$$c_t = c_t^r\,(1-\mu)\,\frac{\bar{C}^r}{\bar{C}}+c_t^n\,\mu\,\frac{\bar{C}^n}{\bar{C}} \tag{4.37}$$

Wage dynamics:

$$\begin{aligned} w_t = {} & \tfrac{\beta}{1+\beta}\,w_{t+1}+\tfrac{1}{1+\beta}\,w_{t-1}+\pi_{t+1}\,\tfrac{\beta}{1+\beta}-\pi_t\,\tfrac{1+\beta\,\omega^w}{1+\beta}+\pi_{t-1}\,\tfrac{\omega^w}{1+\beta}-\tfrac{1}{1+\beta} \\ & \tfrac{(1-\beta\,\theta^w)\,(1-\theta^w)}{\theta^w\left(1+\frac{\varphi\,(1+\lambda^w)}{\lambda^w}\right)}\,(w_t-mrs_t) \end{aligned} \tag{4.38}$$

Marginal rate of substitution (between consumption and labor):

$$mrs_t = \varphi\,l_t+\frac{\sigma}{1-h}\left(c_t^r-h\,c_{t-1}^r\right)+\tau_t^w\,\frac{\bar{\tau}^w}{1-\bar{\tau}^w}+\frac{\bar{\tau}^c}{1+\bar{\tau}^c}\,\tau_t^c+\epsilon_t^l \tag{4.39}$$

Private investment Euler equation:

$$i_t = tq_t\,\frac{1}{\varkappa\,(1+\beta)}+\frac{1}{1+\beta}\,i_{t-1}+\frac{\beta}{1+\beta}\,i_{t+1}-\frac{1}{1+\beta}\left(\beta\,\epsilon_{t+1}^i-\epsilon_t^i\right) \tag{4.40}$$

where $\varkappa = 1/S"(1) > 0$

Shadow cost of private capital:

$$\begin{aligned} q_t = {} & \tfrac{\bar{r}^k\left(1-\bar{\tau}^k\right)}{1-\delta+\bar{r}^k\left(1-\bar{\tau}^k\right)}\left(r_{t+1}^k-\tfrac{\bar{\tau}^k}{1-\bar{\tau}^k}\,\tau_{t+1}^k\right)+\tfrac{1-\delta}{1-\delta+\bar{r}^k\left(1-\bar{\tau}^k\right)}\,q_{t+1} \\ & +\pi_{t+1}-r_t+\eta_t^q \end{aligned} \tag{4.41}$$

Capital utilization:

$$\omega_t = \frac{1}{\kappa}\left(r_t^k-\frac{\bar{\tau}^k}{1-\bar{\tau}^k}\,\tau_t^k\right) \tag{4.42}$$

where: $\kappa = \Psi'(1)/\Psi''(1)$.

Privat capital law of motion:

$$k_t^p = (1-\delta)\,k_{t-1}^p+\delta\,i_t \tag{4.43}$$

Firms

Marginal cost:

$$mc_t = (1-\alpha)\,w_t+\alpha\,r_t^k-z_t-\zeta\,k_{t-1}^g \tag{4.44}$$

Labor demand:

$$l_t = k^p_{t-1} + \omega_t + r^k_t - w_t \tag{4.45}$$

Phillips curve:

$$\pi_t = \pi_{t+1} \frac{\beta}{1+\beta\,\omega^p} + \frac{\omega^p}{1+\beta\,\omega^p}\,\pi_{t-1} + \frac{(1-\beta\,\theta^p)\,(1-\theta^p)}{(1+\beta\,\omega^p)\,\theta^p}\,(mc_t + \eta^{cp}_t) \tag{4.46}$$

Fiscal authority

Government consumption:

$$g^c_t = y_{t-1}\,(-\rho_{gc,y}) - b_{t-1}\,\rho_{gc,b} + \epsilon^{gc}_t \tag{4.47}$$

Government investment:

$$g^i_t = (-\rho_{gi,y})\,y_{t-1} - \rho_{gi,b}\,b_{t-1} + \epsilon^{gi}_t \tag{4.48}$$

Government transfers:

$$tr_t = l_t\,(-\rho_{tr,l}) - b_{t-1}\,\rho_{tr,b} + \epsilon^{tr}_t \tag{4.49}$$

Consumption tax rate:

$$\tau^c_t = \rho_{\tau c,y} y_{t-1} + \rho_{\tau c,b} b_{t-1} + \epsilon^{\tau c}_t \tag{4.50}$$

Labor tax rate:

$$\tau^w_t = \rho_{\tau w,y} y_{t-1} + \rho_{\tau w,b} b_{t-1} + \epsilon^{\tau w}_t \tag{4.51}$$

Capital tax rate:

$$\tau^k_t = \rho_{\tau k,y} y_{t-1} + \rho_{\tau k,b} b_{t-1} + \epsilon^{\tau k}_t \tag{4.52}$$

Public capital law of motion:

$$k^g_t = (1-\delta^g)\,k^g_{t-1} + \delta^g g^i_t \tag{4.53}$$

Government budget constraint:

$$\begin{aligned} \tfrac{\bar{B}}{\bar{Y}} b_t = \; & \tfrac{\bar{TR}}{\bar{Y}}\, tr_t + \tfrac{\bar{B}}{\bar{Y}}\, \tfrac{1}{\beta}\,(b_{t-1} + r_{t-1} - \pi_t) + \tfrac{\bar{G}^c}{\bar{Y}}\, g^c_t + \tfrac{\bar{G}^i}{\bar{Y}}\, g^i_t - \bar{\tau}^c\, \tfrac{\bar{C}}{\bar{Y}}\,(\tau^c_t + c_t) \\ & -\bar{\tau}^w\, \tfrac{\bar{W}\bar{L}}{\bar{Y}}\,(l_t + w_t + \tau^w_t) - \bar{r}^k\,\bar{\tau}^k\, \tfrac{\bar{K}}{\bar{Y}}\,\left(k^p_{t-1} + \omega_t + r^k_t + \tau^k_t\right) \end{aligned} \tag{4.54}$$

Monetary authority and euro area aggregates

Taylor Rule:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)\rho_\pi \pi_{EA,t} + \rho_y y_{EA,t} + \eta^r_t \tag{4.55}$$

Euro area inflation:

$$\pi_{EA,t} = \phi^{DE}\pi + \left(1 - \phi^{DE}\right)\pi_t^{rea} \tag{4.56}$$

Euro area output gap:

$$y_{EA,t} = \phi^{DE}y + \left(1 - \phi^{DE}\right)y_t^{rea} \tag{4.57}$$

Aggregation and market clearing

Production function (from (4.8)):

$$y_t = \xi\,\left(\zeta\,k_{t-1}^g + z_t + \alpha\,k_{t-1}^p + \alpha\,\omega_t + (1-\alpha)\;l_t\right) \tag{4.58}$$

where $\xi = 1 + \Phi/\bar{Y}$.
Technology:

$$z_t = \rho_z z_{t-1} + \eta_t^z \tag{4.59}$$

Goods market clearing:

$$\begin{aligned} y_t = \;& \tfrac{\bar{C}}{\bar{I}}c_t + \tfrac{\delta\bar{K}}{\bar{Y}}i_t + \tfrac{\bar{G}^c}{\bar{Y}}\,g_t^c + \tfrac{\bar{G}^i}{\bar{Y}}g_t^i + \omega_t\left(1-\bar{\tau}^k\right)\,\bar{r}^k\,\tfrac{\bar{K}}{\bar{Y}} \\ & + \left(1 - \tfrac{\bar{C}}{\bar{C}} - \tfrac{\delta\bar{K}}{\bar{Y}} - \tfrac{\bar{G}^c}{\bar{Y}} - \tfrac{\bar{G}^i}{\bar{Y}} - \left(1-\bar{\tau}^k\right)\,\bar{r}^k\,\tfrac{\bar{K}}{\bar{Y}}\right)tb_t \end{aligned} \tag{4.60}$$

Shocks and AR(1) processes

Technology shock:

$$z_t = \rho_z\,z_{t-1} + \eta_t^z \tag{4.61}$$

Investment shock:

$$\epsilon_t^i = \rho_i\,\epsilon_{t-1}^i + \eta_t^i \tag{4.62}$$

Preference shock:

$$\epsilon_t^p = \rho_p\,\epsilon_{t-1}^p + \eta_t^p \tag{4.63}$$

Labor supply shock:

$$\epsilon_t^l = \rho_l\,\epsilon_{t-1}^l + \eta_t^l \tag{4.64}$$

Government consumption shock:

$$\epsilon_t^{gc} = \rho_{gc}\,\epsilon_{t-1}^{gc} + \eta_t^{gc} \tag{4.65}$$

Government investment shock:

$$\epsilon_t^{gi} = \rho_{gi}\,\epsilon_{t-1}^{gi} + \eta_t^{gi} \tag{4.66}$$

Government transfer shock:

$$\epsilon_t^{tr} = \rho_{tr}\,\epsilon_{t-1}^{tr} + \eta_t^{tr} \tag{4.67}$$

Consumption tax rate shock:

$$\epsilon_t^{\tau c} = \rho_{\tau c}\,\epsilon_{t-1}^{\tau c} + \eta_t^{\tau c} \tag{4.68}$$

Labor tax rate shock:

$$\epsilon_t^{\tau w} = \rho_{\tau w}\,\epsilon_{t-1}^{\tau w} + \eta_t^{\tau w} \tag{4.69}$$

Capital tax rate shock:

$$\epsilon_t^{\tau k} = \rho_{\tau k}\,\epsilon_{t-1}^{\tau k} + \eta_t^{\tau k} \tag{4.70}$$

Trade balance:

$$tb_t = \rho_{tb}\,tb_{t-1} + \eta_t^{tb} \tag{4.71}$$

Steady state relationships

The interest rate:

$$\bar{r} = \frac{1}{\beta} \tag{4.72}$$

The marginal cost:

$$\bar{mc} = 0.80 \tag{4.73}$$

Labor supply:

$$\bar{l} = \frac{1}{3} \tag{4.74}$$

Mark-up:

$$\xi = \frac{1}{\bar{mc}} \tag{4.75}$$

Privat rental rate of capital:

$$\bar{r}_k = \frac{1}{1-\bar{\tau}_k}\left(\frac{1}{\beta} - (1-\delta)\right) \tag{4.76}$$

Wage:

$$\bar{w} = \left(\frac{\delta^g\,(1-\alpha)}{\frac{\bar{G}^i}{\bar{Y}}\,\bar{L}}\right)^{\frac{\zeta}{\zeta-(1-\alpha)}} \left(\chi\left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\bar{r}_k^{\alpha}\right)^{\frac{1}{\zeta-(1-\alpha)}} \tag{4.77}$$

Capital stock:

$$\bar{K}^p = \bar{L}\,\frac{\alpha}{1-\alpha}\,\frac{\bar{W}}{\bar{r}^k} \tag{4.78}$$

Production:

$$\begin{aligned}\bar{Y} = \ & \bar{r}_k^{\alpha} \left(\tfrac{1}{\alpha}\right)^{\alpha} \left(\tfrac{1}{1-\alpha}\right)^{1-\alpha} \bar{K}^{\alpha} \bar{L}^{1-\alpha} \times \\ & \left(\left(\frac{\delta^g (1-\alpha)}{\frac{\bar{G}^i}{\bar{Y}} \bar{L}} \right)^{\frac{\zeta}{\zeta-(1-\alpha)}} \left(\chi \left(\tfrac{1}{1-\alpha}\right)^{1-\alpha} \left(\tfrac{1}{\alpha}\right)^{\alpha} \bar{r}_k^{\alpha} \right)^{\frac{1}{\zeta-(1-\alpha)}} \right)^{1-\alpha}\end{aligned} \tag{4.79}$$

Consumption of optimizing households:

$$\begin{aligned}\bar{C}^r = \ & \tfrac{\bar{W}\bar{L}}{(1+\bar{\tau}^c)(1-\mu)} \left(\tfrac{1}{1-\alpha} \left(1 - \tfrac{\bar{B}}{\bar{Y}} (1-\bar{r}) + \tfrac{\bar{TR}}{\bar{Y}} \right) \right. \\ & \left. - \left(\bar{r}^k \bar{\tau}^k + \delta \right) \tfrac{\alpha}{1-\alpha} \tfrac{1}{\bar{r}^k} - \bar{\tau}^w - \mu \left(1 - \bar{\tau}^w + \tfrac{1}{1-\alpha} \tfrac{\bar{TR}}{\bar{Y}} \right) \right)\end{aligned} \tag{4.80}$$

Consumption of non-optimizing households:

$$\bar{C}^n = \frac{1}{1+\bar{\tau}^c} \left(\bar{W}\bar{L}\,(1-\bar{\tau}^w) + \frac{\bar{TR}}{\bar{Y}}\,\bar{Y} \right) \tag{4.81}$$

Total consumption:

$$\bar{C} = (1-\mu)\,\bar{C}^r + \mu\,\bar{C}^n \tag{4.82}$$

Public capital stock:

$$\bar{K}^g = \left(\chi\,\bar{r}_k^{\alpha} \left(\frac{1}{1-\alpha} \right)^{1-\alpha} \left(\frac{1}{\alpha} \right)^{\alpha} \bar{W}^{1-\alpha} \right)^{\frac{1}{\zeta}} \tag{4.83}$$

Appendix E: Figures

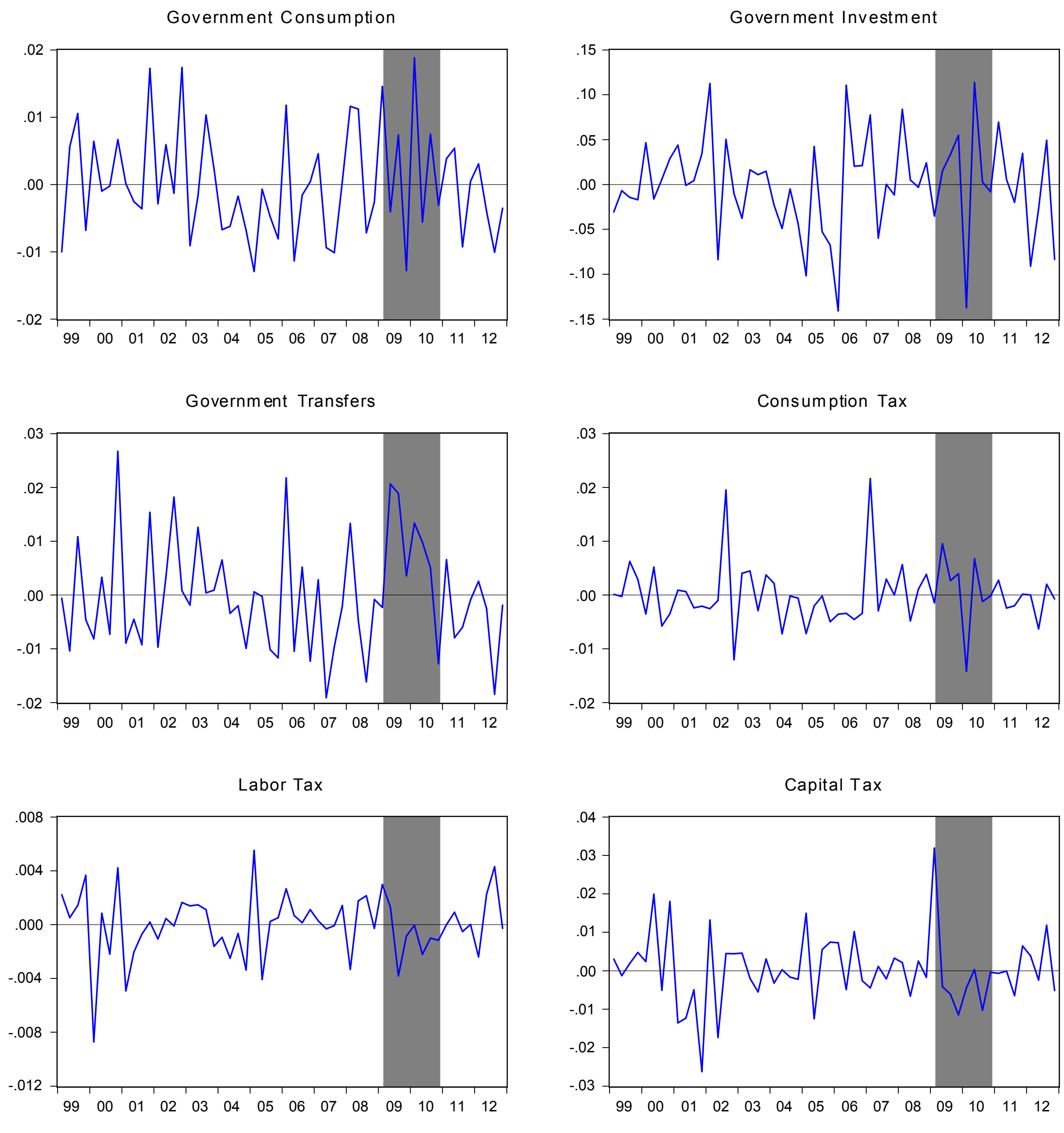

Figure 4.1: Smoothed fiscal shocks

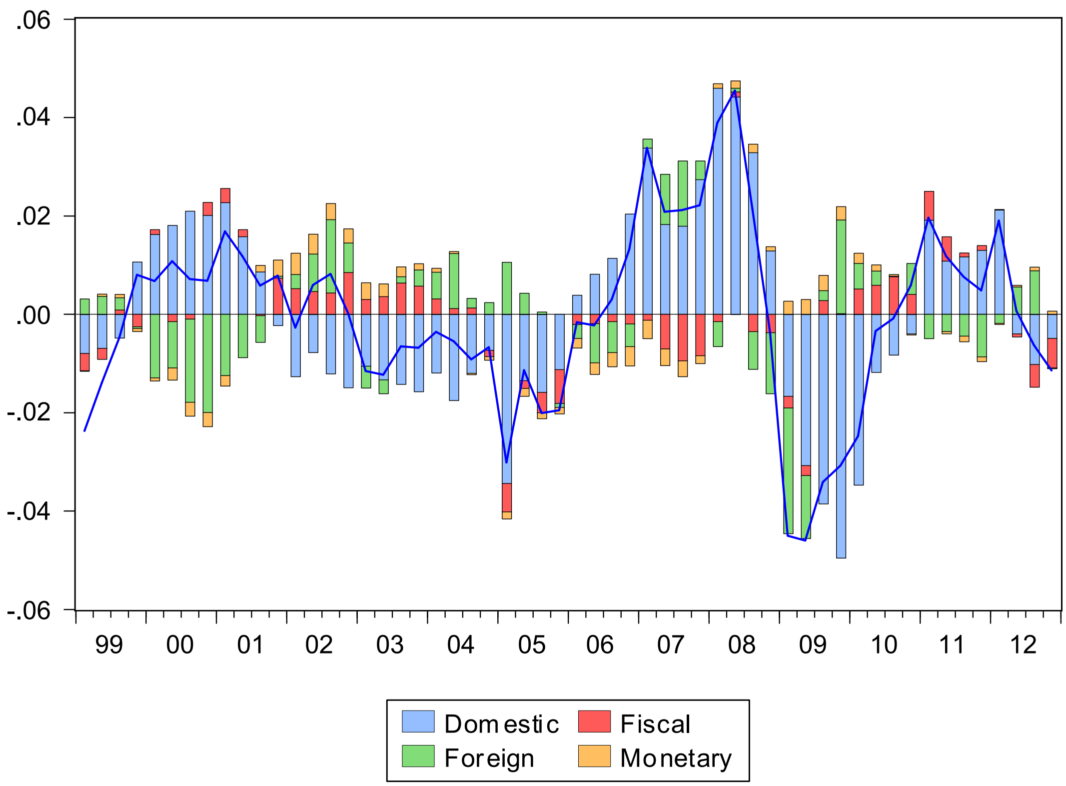

Figure 4.2: Historical decomposition of the German output gap (solid line). Contributions of the 16 model shocks. Domestic shocks include all non-fiscal domestic disturbances, fiscal shocks contain the six fiscal rule disturbances, foreign shocks consist of the trade balance shock and shocks to the rest of the euro area GDP and inflation.

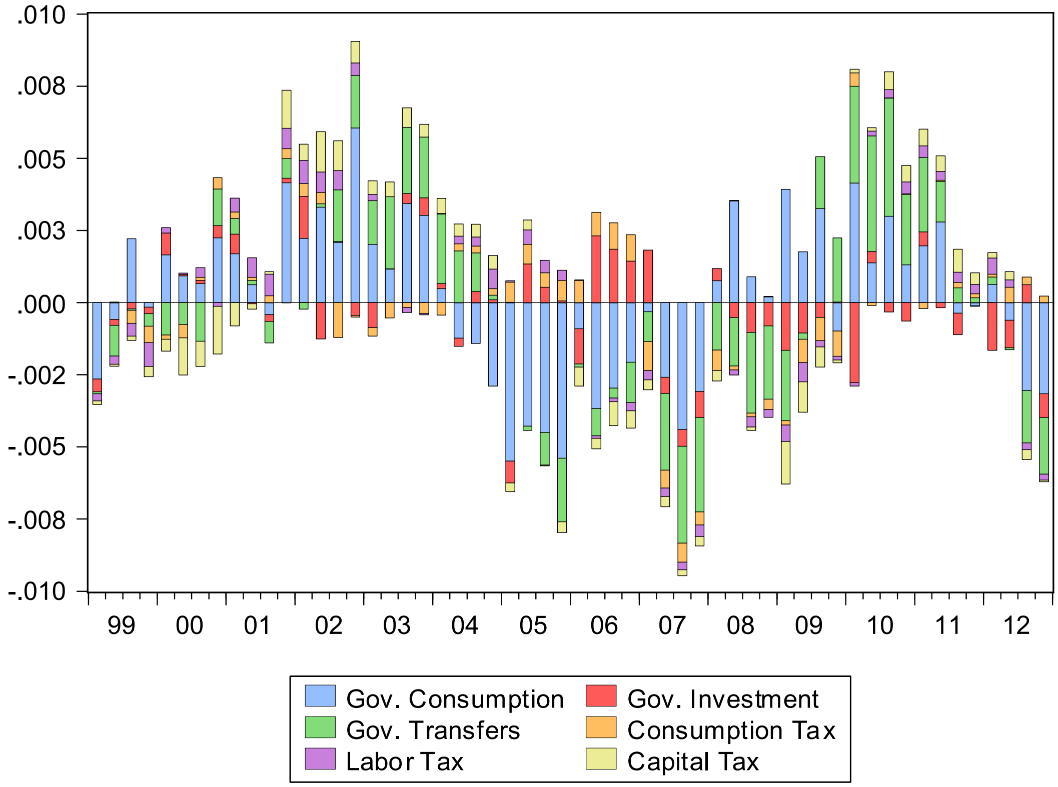

Figure 4.3: Historical decomposition of the German output gap: contribution of fiscal shocks

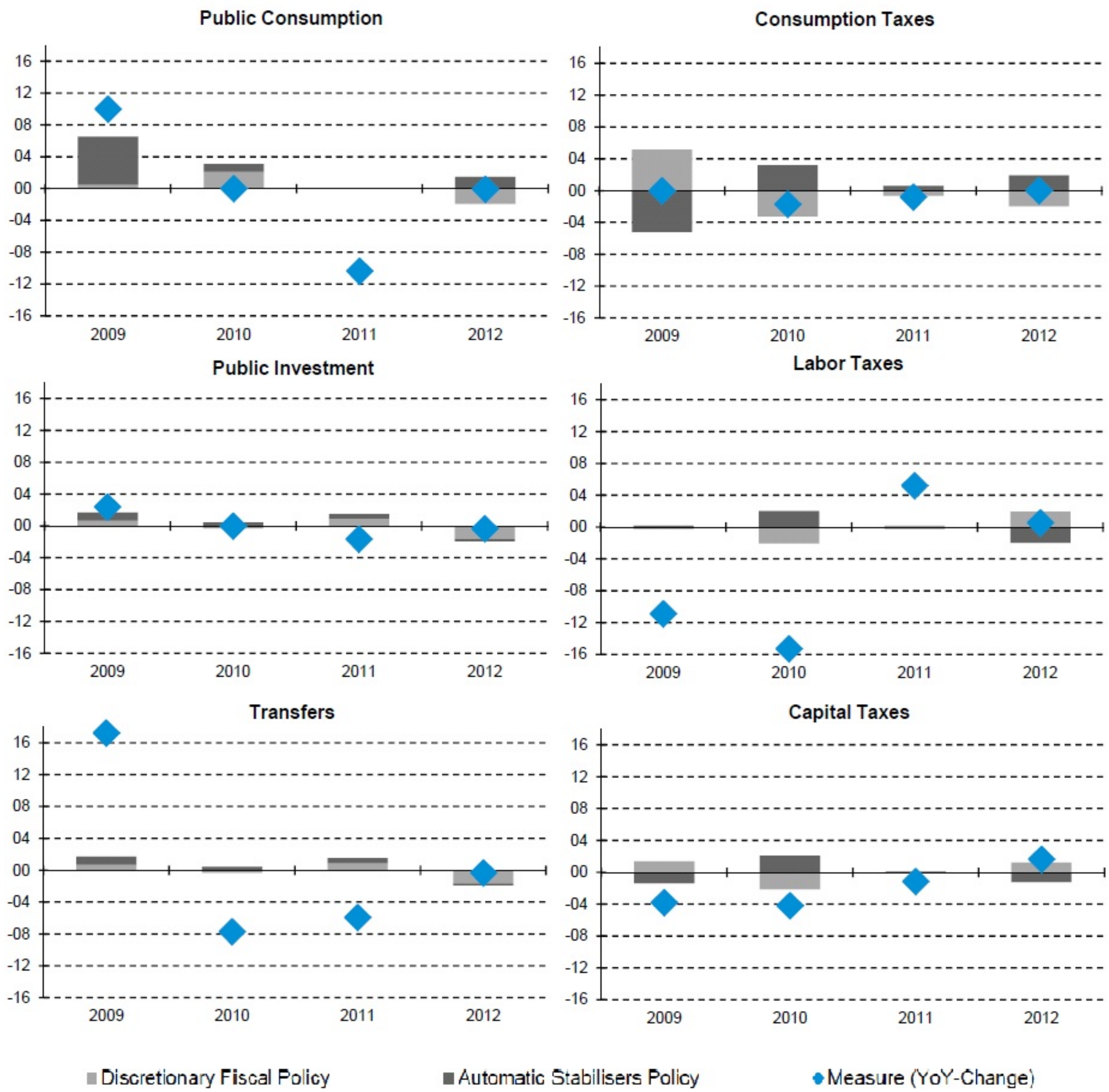

Figure 4.4: Discretionary fiscal measures: Amount announced vs. the models' shocks. Comparison of the year-to-year change of the size of the official measures with the yearly average fiscal policies as they were identified in the model. For some instruments and time periods the sum of the models' shocks plus the automatic stabilizers reaches a size that is similar to the magnitude of the announced fiscal measures. However, there are also several observations when this is not the case. Yet, this should not come as a surprise. A direct comparison of identified shocks and the official announced numbers is prone to misunderstandings and hence should be dealt with carefully.

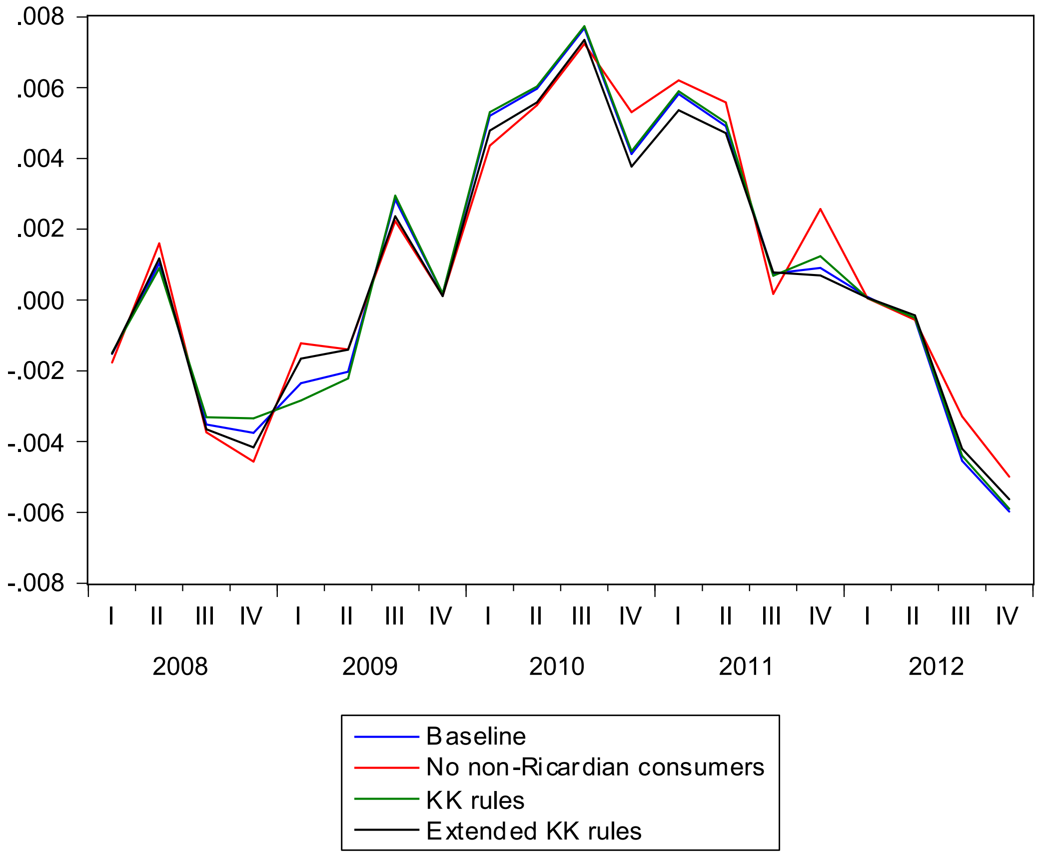

Figure 4.5: Contribution of fiscal shocks to output under different model specifications

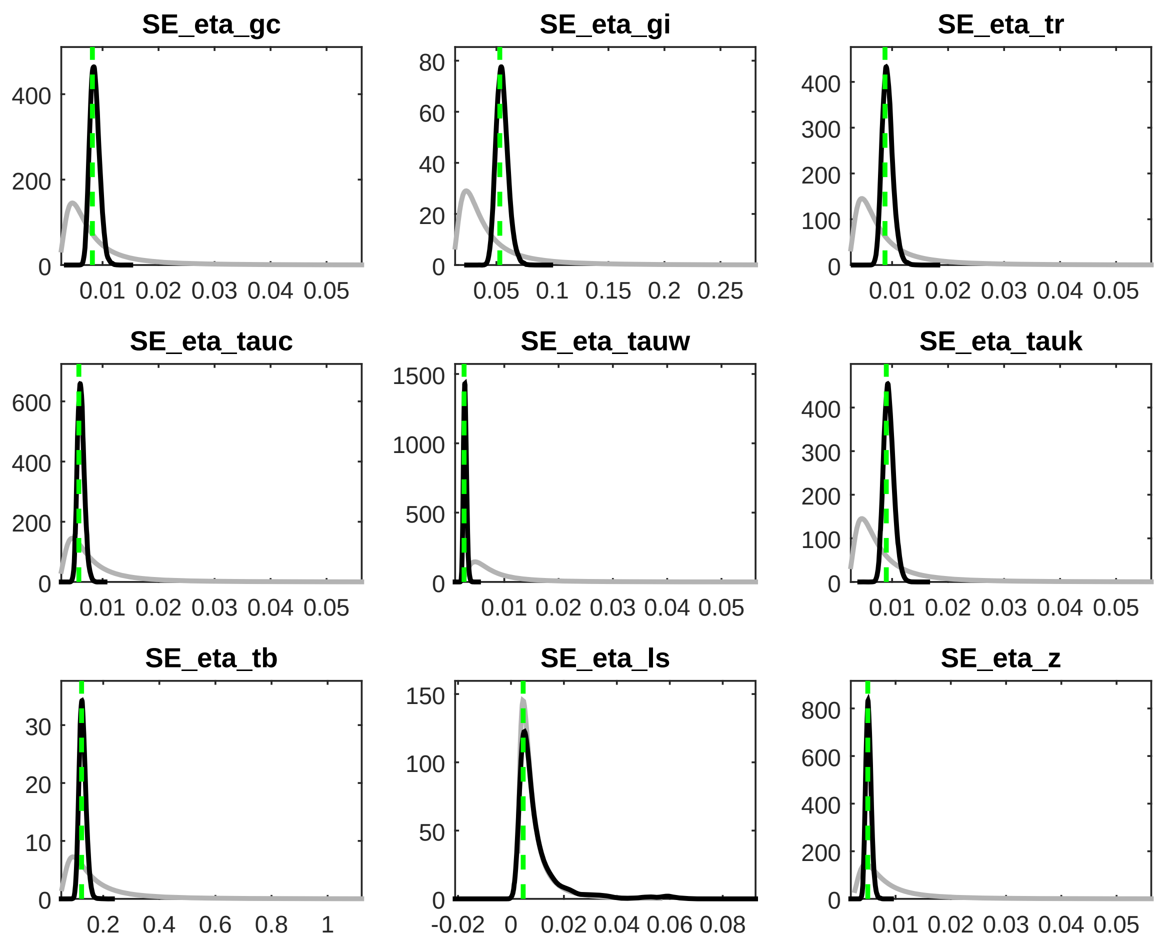

Figure 4.6: Priors and posteriors

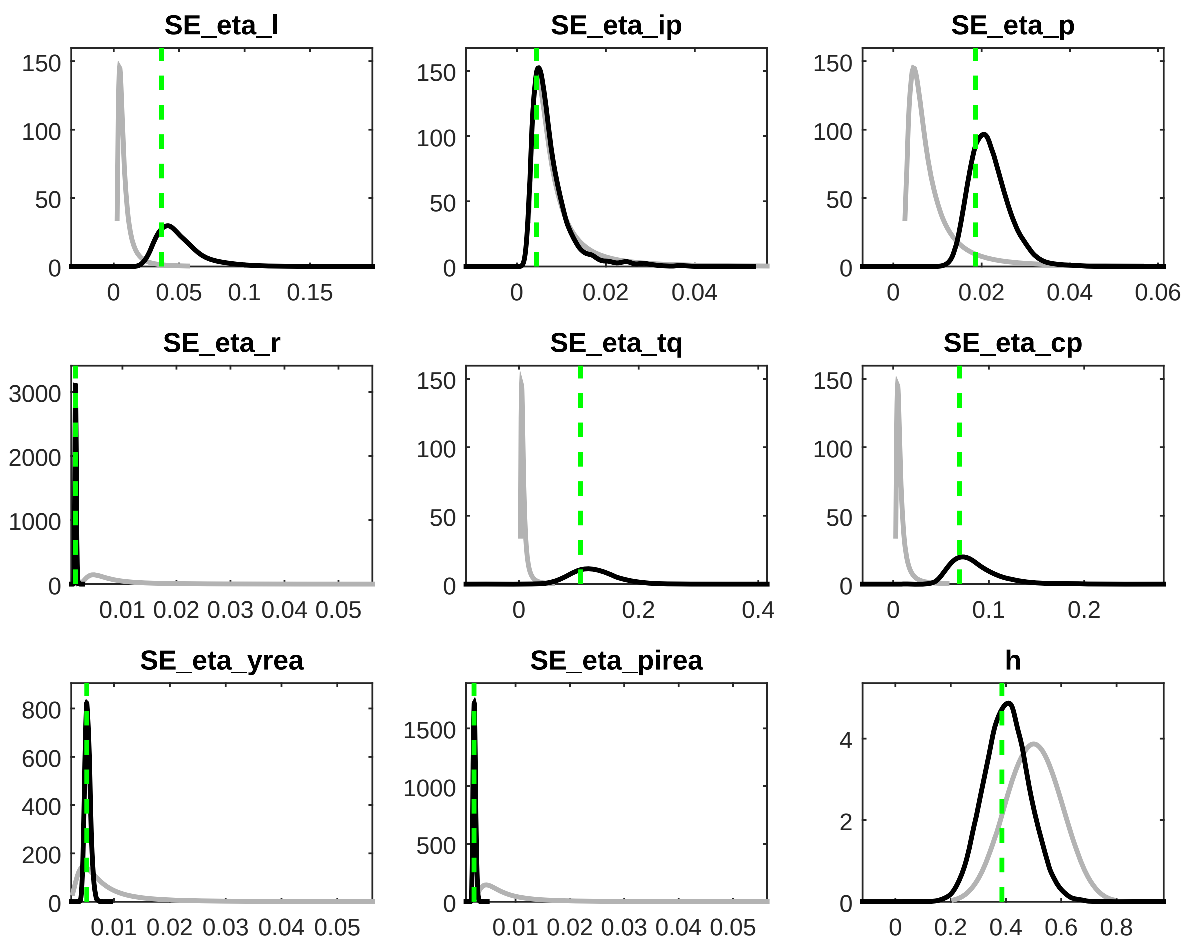

Figure 4.7: Priors and posteriors (cont.)

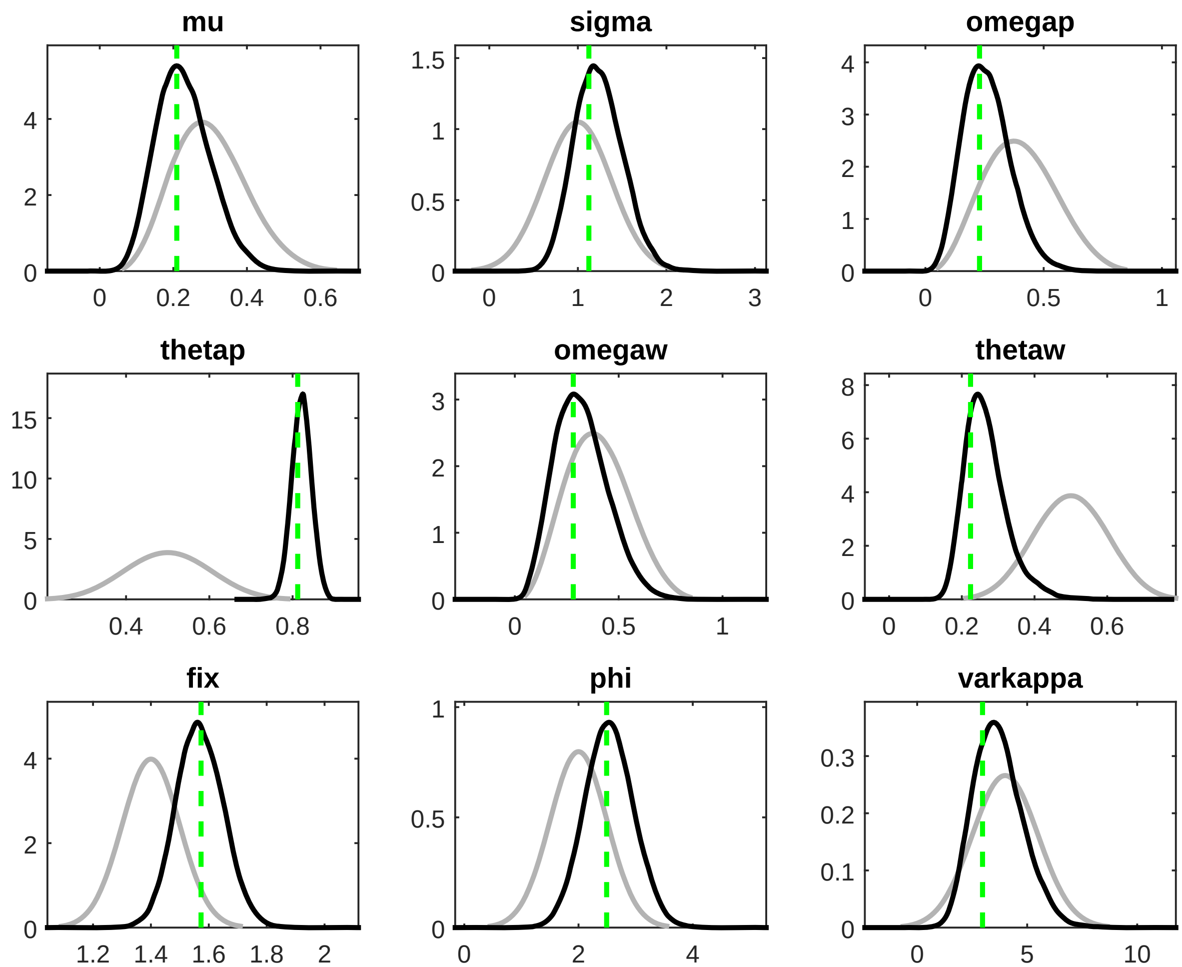

Figure 4.8: Priors and posteriors (cont.)

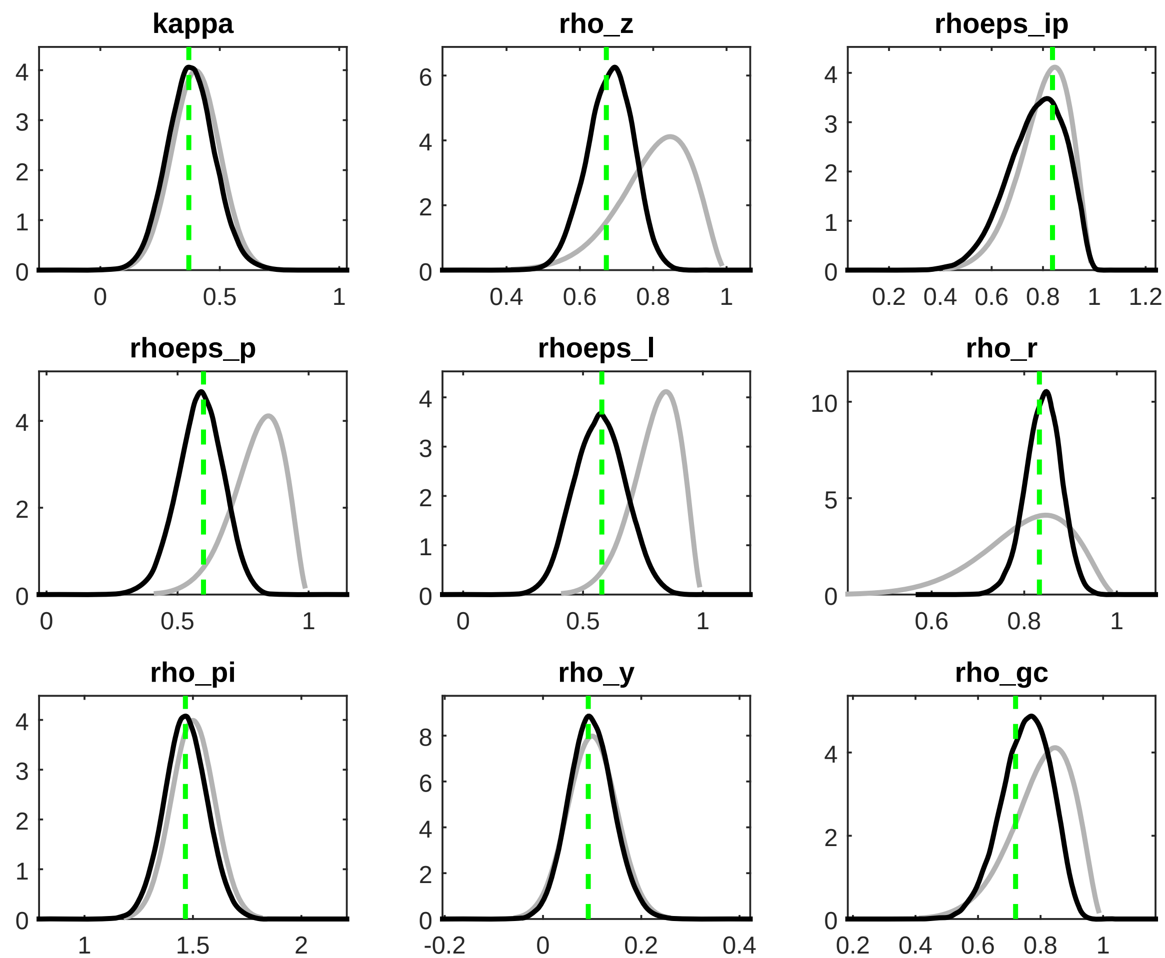

Figure 4.9: Priors and posteriors (cont.)

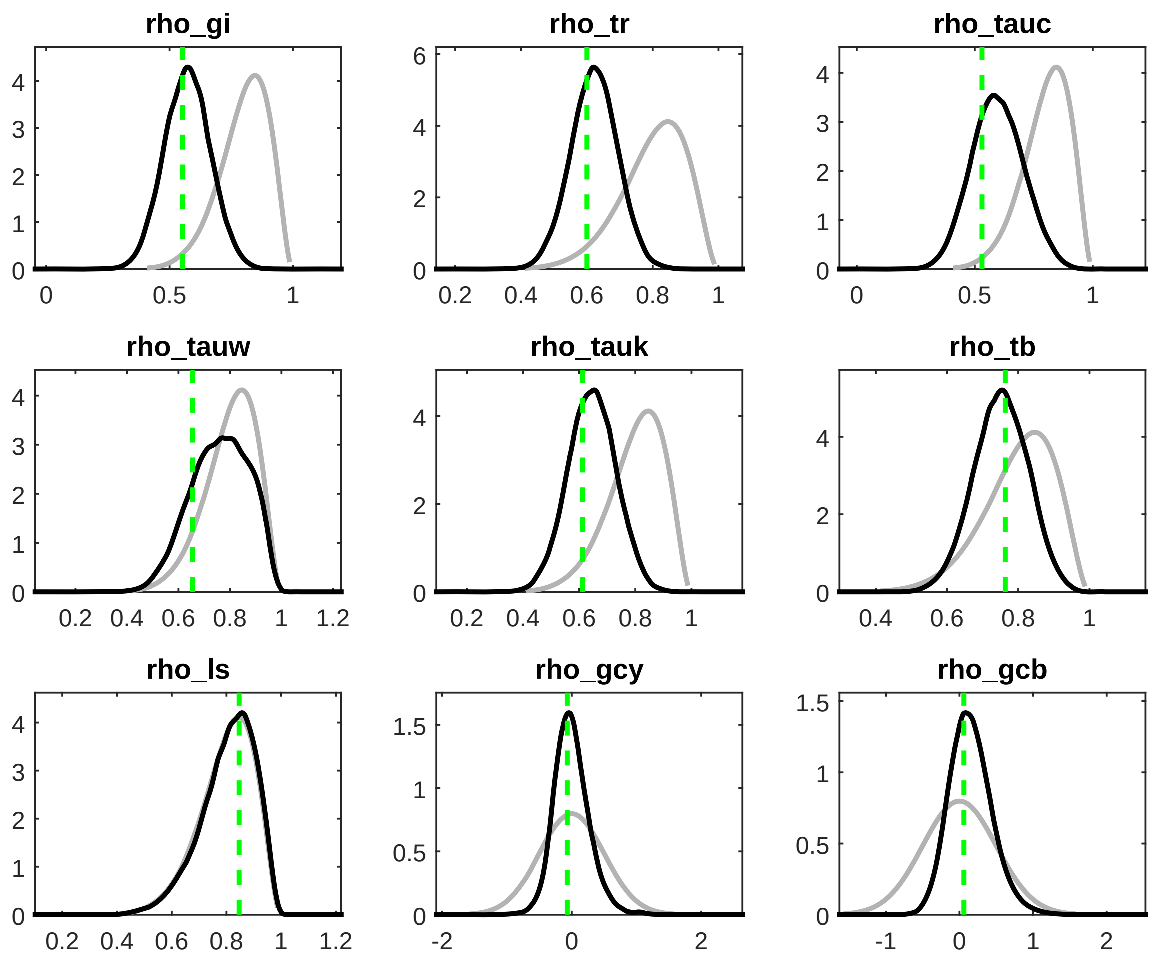

Figure 4.10: Priors and posteriors (cont.)

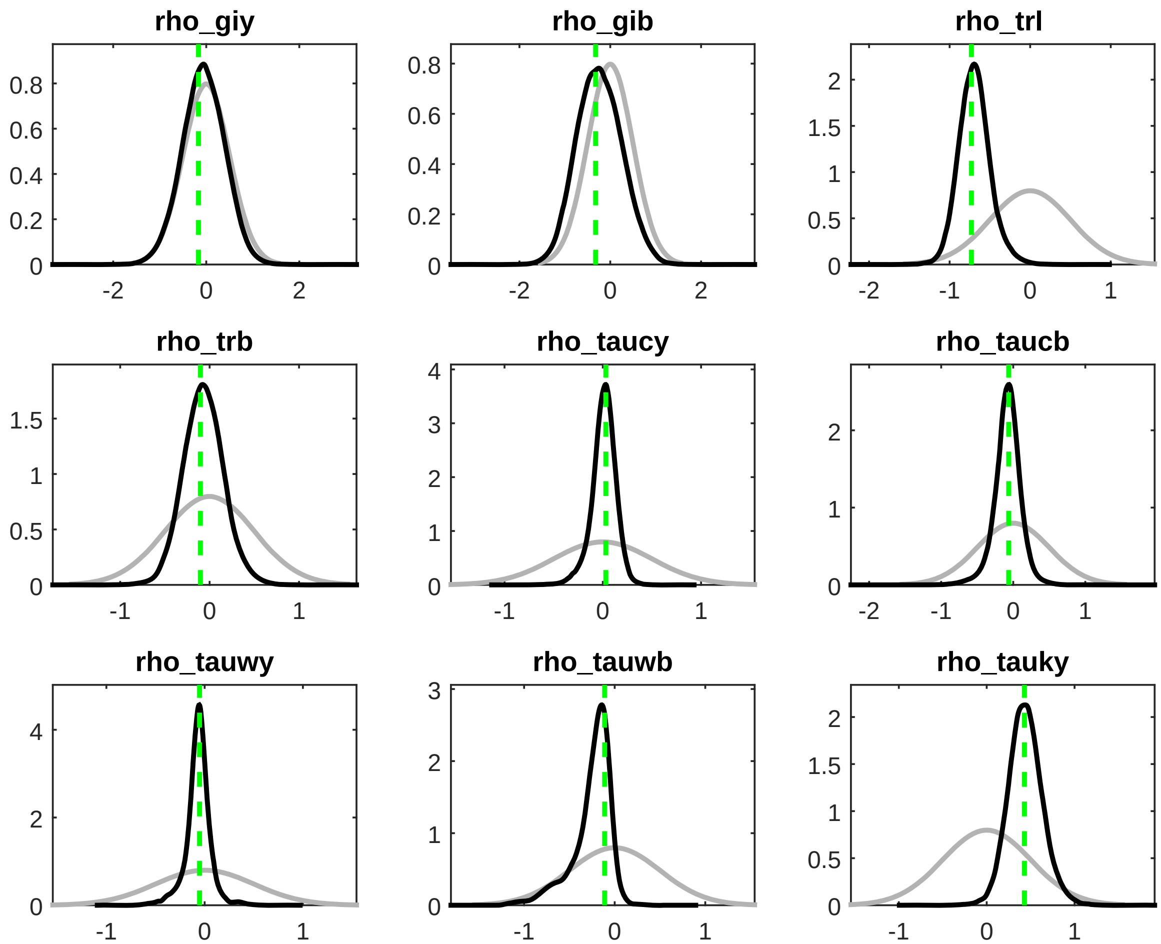

Figure 4.11: Priors and posteriors (cont.)

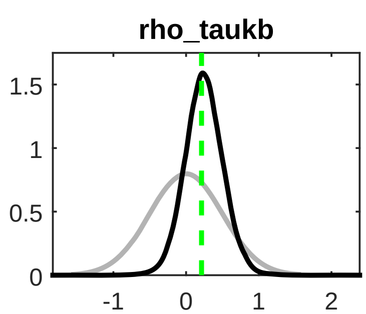

Figure 4.12: Priors and posteriors (cont.)