**Labour Market Modelling within a DSGE Approach**

Tonner, Jaromír ; Tvrz, Stanislav ; Vašíček, Osvald
2015

WORKING PAPER SERIES 6

2015

Jaromír Tonner, Stanislav Tvrz, Osvald Vašíček

# Labour Market Modelling within a DSGE Approach

CZECH NATIONAL BANK

# WORKING PAPER SERIES

**Labour Market Modelling within a DSGE Approach**

Jaromír Tonner
Stanislav Tvrz
Osvald Vašíček

6/2015

**CNB WORKING PAPER SERIES**

The Working Paper Series of the Czech National Bank (CNB) is intended to disseminate the results of the CNB's research projects as well as the other research activities of both the staff of the CNB and collaborating outside contributors, including invited speakers. The Series aims to present original research contributions relevant to central banks. It is refereed internationally. The referee process is managed by the CNB Research Department. The working papers are circulated to stimulate discussion. The views expressed are those of the authors and do not necessarily reflect the official views of the CNB.

Distributed by the Czech National Bank. Available at http://www.cnb.cz.

Reviewed by: Kai Christoffel (European Central Bank)
Stephen Millard (Bank of England)
Iva Pejsarová (Czech National Bank)

Project Coordinator: Jan Babecký

# Labour Market Modelling within a DSGE Approach

Jaromír Tonner, Stanislav Tvrz, and Osvald Vašíček *

## Abstract

The goal of this paper is to find a suitable way of modelling the main labour market variables in the framework of the CNB's core DSGE model. The model selection criteria are: the predictive ability for unemployment, the change in the overall predictive ability in comparison to the baseline model and the extent of the required model change. We find that the incorporation of a modified Galí, Smets and Wouters (2011) labour market specification allows us to predict unemployment with an acceptable forecast error. At the same time it leads to a moderate improvement in the overall predictive ability of the model and requires only minor adjustments to the model structure. Thus, it should be preferred to more complicated concepts that yield a similar improvement in predictive ability. We also came to the conclusion that the concept linking unemployment and the GDP gap is promising. However, its practical application would require (additional) improvement in the accuracy of the consumption prediction. As a practical experiment, we compare the inflation pressures arising from nominal wages and the exchange rate in the baseline model and in alternative specifications. The experiment is motivated by the use of the exchange rate as an additional monetary policy instrument by the CNB since November 2013 in an environment of near-zero interest rates and growing disinflationary pressures. We find that the baseline model tends to forecast higher nominal wage growth and lower exchange rate depreciation than the models with more elaborate labour markets. Therefore, the alternative models would probably have identified an even higher need for exchange rate depreciation than the baseline model did.

## Abstrakt

Cílem příspěvku je nalézt vhodný přístup k modelování hlavních proměnných trhu práce v rámci jádrového DSGE modelu ČNB. Kritérii výběru vhodné modelové specifikace jsou: kvalita predikce nezaměstnanosti, změna celkové predikční schopnosti ve srovnání s výchozím modelem a rozsah nezbytných modelových úprav. Zjistili jsme, že varianta modelu trhu práce podle Galího, Smetse a Wouterse (2011) umožňuje predikovat nezaměstnanost s přijatelnou chybou. Zároveň tato specifikace mírně zlepšuje celkovou predikční schopnost modelu a vyžaduje modelové úpravy relativně malého rozsahu. Proto doporučujeme tento přístup spíše než složitější koncepty, které dosahují podobného zlepšení predikčních schopností modelu. Také přístup propojující nezaměstnanost s mezerou výstupu se ukazuje jako nadějný, jeho praktické využití je ale podmíněno (dodatečným) zvýšením přesnosti predikce spotřeby. Jako praktický experiment jsme se rozhodli pro srovnání rozložení inflačních tlaků pramenících z růstu nominálních mezd a oslabování směnného kurzu ve výchozím modelu a v jeho alternativních specifikacích. Experiment je motivován rozhodnutím z listopadu 2013 používat devizový kurz jako další nástroj uvolňování měnových

* Jaromír Tonner, (Corresponding author), Macroeconomic Forecasting Division, Czech National Bank (jaromir.tonner@cnb.cz) and Faculty of Economics and Administration, Masaryk University
Stanislav Tvrz, Economic and Monetary Analysis Department, National Bank of Slovakia (stanislav.tvrz@nbs.sk) and Faculty of Economics and Administration, Masaryk University
Osvald Vašíček, Faculty of Economics and Administration, Masaryk University (osvald@econ.muni.cz)
This work was supported by Czech National Bank Research Project No. B2/2013. It was also supported by funding of specific research at the Faculty of Economics and Administration, project MUNI/A/1235/2014. This support is gratefully acknowledged. The authors would like to thank Kai Christoffel, Stephen Millard and Iva Pejsarová for their helpful comments. The views expressed here are those of the authors and do not necessarily reflect the position of the Czech National Bank or the National Bank of Slovakia.

podmínek, ke kterému došlo v prostředí téměř nulových úrokových sazeb a rostoucích dezinflačních tlaků. Zjistili jsme, že výchozí model má ve srovnání s modely s propracovanějším trhem práce tendenci predikovat vyšší růst nominálních mezd a méně výrazné oslabení směnného kurzu. Z toho vyplývá, že alternativní modely by pravděpodobně indikovaly ještě vyšší potřebu oslabení kurzu než výchozí model.

**JEL Codes:** C53, E32, E37.
**Keywords:** DSGE, labour market, Nash bargaining, right to manage.

## Nontechnical Summary


The aim of our research is to compare and evaluate various ways of incorporating the labour market into the standard New Keynesian DSGE framework of the CNB's core prediction model (called the g3 model). Labour market variables are important indicators of economic activity and have the potential to improve the overall performance of the model. Changes to the model should take greater account of observed labour market variables (unemployment, employment, labour force, hours worked) in the determination of the position of the economy in the business cycle and, of course, in forecasting.

We considered simple data-driven modifications of the current labour market structure as well as more sophisticated theoretical concepts. First, various choices of observed labour market variables and their links to the rest of the model were considered. Different structural concepts introducing additional assumptions into the model were investigated next. Finally, we examined the properties of multiple search and matching concepts.

The main model selection criterion was the predictive ability for unemployment. At the same time, we required the model modification not to cause any significant deterioration in the predictive ability for the remaining observables. In fact, we preferred model specifications that lead to an improvement in the overall predictive ability in comparison to the baseline model. We measured the predictive ability of alternative models with the use of in-sample simulation. Subsequently, we also checked other model properties such as shock decompositions and impulse responses. Finally, we assessed the magnitude and feasibility of the changes to the existing model structure with the aim of keeping the model as simple as possible.

We came to the conclusion that simple changes to the observable variables deliver only partial improvements in forecasting power for some variables while at the same time leading to a deterioration for the rest. Further, we found the concept which links unemployment and the GDP gap to be very promising for predicting all model variables except consumption. Potentially, search and matching concepts could lead to improvements in the forecasting power, but the extent of the model change is substantial, making this approach unfeasible. The preferred type of modification, one that delivers a comparable improvement in forecasting power while keeping the extent of the necessary model changes within acceptable bounds, is the concept of Galí et al. (2011), which links unemployment to the labour market markup. This concept achieved one of the lowest prediction errors for unemployment while leading to a moderate improvement in the predictive power for the remaining observables in comparison to the baseline model. A necessary condition for obtaining such a result is to reduce employment elasticity. This reduction is supported by the fact that the unemployment gap is about one third of the size of the lagged GDP gap.

As a practical experiment, we considered the inflation pressures arising from nominal wages and the exchange rate during the crisis. The Czech National Bank started using the koruna exchange rate as a monetary policy instrument in autumn 2013, when interest rates had reached the zero lower bound and further easing of monetary policy was required. We found that the baseline model tends to forecast higher nominal wage growth and lower exchange rate depreciation than the models with more elaborate labour market concepts. Thus, models with elaborate labour markets would probably have identified an even higher need for a weaker exchange rate in order to deliver the desired inflationary pressures than the baseline g3 model did.

# 1. Introduction

## 1.1 Motivation

The aim of this research is to compare and evaluate various ways of incorporating the labour market into the standard New Keynesian DSGE framework of the CNB's core prediction model (called the g3 model[1]). Labour market variables are important indicators of economic activity and have the potential to improve the overall performance of the model. Specific model changes should take greater account of observed labour market variables (unemployment, employment, labour force, hours worked) in the determination of the position of the economy in the business cycle and, of course, in forecasting.

We considered simple modifications of the current labour market structure and also more sophisticated concepts. First, various choices of observed labour market variables and their links to the rest of the model were considered. Different structural concepts introducing additional assumptions into the model were investigated next. Finally, we examined the properties of multiple search and matching concepts.

The main model selection criterion was the predictive ability for unemployment. At the same time, we required the model modification not to cause any significant deterioration in the predictive ability for the remaining observables. In fact, we preferred model specifications that lead to an improvement in the overall predictive ability in comparison to the baseline model. Subsequently, we also checked other model properties such as shock decompositions and impulse responses. Finally, we assessed the magnitude and feasibility of the changes to the existing model structure with the aim of keeping the model as simple as possible.

Each model change is described in general. If possible, we present a more detailed analysis in the Appendix. For more complex concepts, only literature references are provided.

The rest of the paper is organized as follows. The remainder of this section surveys related literature. Section 2 outlines the g3 labour market. Section 3 then briefly describes alternative labour markets incorporated into g3. Section 4 contains an empirical analysis, while Section 5 evaluates the monetary policy (MP) experiment. The last section concludes and the Appendix contains additional materials, mostly derivations, figures and tables.

## 1.2 Related Literature

The majority of current DSGE models do not explicitly embed a labour market with unemployment linked to real economic activity. In 'standard' New Keynesian DSGE models, movements in the labour market are captured by varying hours worked (intensive margin) or by the choice of whether or not to participate in the labour market (extensive margin). Many authors (e.g. Blanchard, 2008; Christiano et al., 2011) point out the limitations of that approach, as unemployment is an important indicator of aggregate resource utilization and an important focus of the policy debate.

Incorporating labour market imperfections into DSGE models is currently one of most discussed issues in the field of macroeconomic modelling. This research has intensified over the last decade, when a lot of authors have implemented a labour market with search and matching (Mortensen and Pissarides, 1994) into the New Keynesian framework. The effects of such labour market frictions within DSGE models with flexible wages but sticky prices are analysed in Walsh (2005) and Tri-

[1] See Andrle et al. (2009) for a description of the CNB's g3 forecasting model.

gari (2009). Christoffel et al. (2009) extend this work, relaxing the assumption of flexible wages by introducing wage rigidity into the framework. Another strand of research has turned to more normative issues, analysing the implications of labour market frictions for monetary policy; examples include Blanchard and Galí (2007), Blanchard and Galí (2010), Faia (2008), Faia (2009) and Thomas (2008). Gertler et al. (2008) and de Walque et al. (2009) analyse models with staggered wage bargaining.

Galí et al. (2011) use a framework where unemployment results from the presence of market power in the labour market, implying a positive average wage markup (a gap between the prevailing wage and the disutility of work for the marginal worker). Fluctuations in the unemployment rate are associated with variations in the average wage markup due to the presence of nominal wage rigidities.

Christiano et al. (2011) use an alternative framework to model unemployment. They include the labour market search and matching framework of Mortensen and Pissarides (1994) and, more recently, Hall (2005a), Hall (2005b), Hall (2006) and Shimer (2007). In their model, the probability of finding a job increases with search effort, and imperfect risk sharing among individuals is a consequence of the non-observability of effort.

A radically different approach to labour market modelling was initiated in a series of papers by Roger Farmer and his co-authors (see Farmer, 2010, for a survey of the beginnings of this research agenda). These papers try to formalize the ideas of Post Keynesian economics in a modern framework of DSGE models and attribute labour market fluctuations and output fluctuations to self-fulfilling prophecies, which formalizes the Keynesian idea of animal spirit. It seems that this approach is able to explain some data features which are hard to explain in a standard New Keynesian framework. However, to the best of our knowledge, this approach has been tested only on small stylized models and not on elaborate models suitable for practical forecasting.

During the past seven years, there has been some interesting research on the Czech labour market. Some papers deal with issues related to institutional features and hence to what New Keynesians would call the natural unemployment rate. Galuščák and Pavel (2012) investigate the effect of net replacement rates on work incentives, contributing to the understanding of the equilibrium level of unemployment. Bičáková (2006) investigates the employment effects of changes in taxes and net benefits.

Other studies deal with labour market rigidities, hence they have implications for the fluctuations of labour market variables over the cycle. For example, Babecký et al. (2008) use a survey at firm level to investigate the determinants of wage and price formation in Czech firms. They find efficiency wage models relevant for wage setting. Babecký et al. (2011) investigate the asymmetric response of firms' labour demand in good times and during a crisis.

Some studies try to distinguish between structural and cyclical factors. Hurník and Navrátil (2005) estimate the time-varying NAIRU to distinguish between the two. Galuščák and Münich (2007) address the issue of structural and cyclical unemployment using movements in Beveridge curve parameters. Brůha (2011), based on euro area labour market models by Brůha et al. (2011) and Proietti and Musso (2007), introduces a macroeconomic Czech labour market structural time series model useful for consistent filtering of trends and cycles and documenting some stylized facts.

## 2. g3 Labour Market

The labour market in the g3 model[2] is currently modelled following Smets and Wouters (2003), and Smets and Wouters (2007) who employ the wage-setting mechanism introduced by Erceg et al. (2000). Monopolistic competition on the supply side of the labour market (i.e. on the side of households) and wage rigidity à la Calvo are assumed and both are represented by time-varying $markup_t^L$. Real wages ($w_t(1-\tau^W)$, where $\tau^W$ is a labour income tax parameter) then balance the marginal rate of substitution between consumption and hours worked

$$w_t(1-\tau^W) = markup_t^L \frac{\kappa}{\lambda_t},$$

where $\lambda_t$ is the shadow price of wealth and $\kappa$ is the scale of hours in utility. On the demand side of the labour market, real wages balance the marginal product of labour in the sector of intermediate products

$$w_t(1-\tau^S) = \frac{\gamma q_t^Y y_t}{ell_t},$$

where $\tau^S$ is a social contribution rate parameter, $\gamma$ is the share of labour in the production function, $q_t^Y$ is the scaled relative marginal cost of intermediate goods, $y_t$ is scaled intermediate product and $ell_t$ is labour. The resulting wage Phillips curve has a margin for job suppliers (calibration 20%) and the rigidity of nominal wages (calibration five quarters)

$$\log\left(\frac{\pi_t^w}{\pi_{t-1}^w}\right) = \beta \log\left(\frac{\pi_{t+1}^w}{\pi_t^w}\right) + \frac{(1-\beta\xi^L)(1-\xi^L)}{\xi^L}\log(markup^L rmc_t^w) + \varepsilon_t^{labor},$$

where $\pi_t^w$ is wage inflation, $\beta$ is the discount factor, $\xi^L$ is the Calvo wage parameter, $markup^L$ is the steady state of $markup_t^L$ and $rmc_t^w$ is the reversed value of $markup_t^L$. There are two labour market observables: the average nominal wage with a small measurement error, and employment with a larger measurement error, i.e. the employment time series is basically not observed (see Figure A2).

## 3. Alternative Labour Market Models

In this section, we introduce the alternative approaches to the incorporation of labour market variables into the baseline model structure that are subsequently evaluated in the rest of the paper. First, we consider a parametric change in the value of the Calvo wage parameter. Next, we propose several alternative modifications of the labour market observables; most importantly, we introduce multiple ways of observing unemployment and linking it to the rest of the model. All the previous model modifications are referred to as *simple* specifications because they are based only on empirical relationships in the observed data. The following model specifications are referred to as *sophisticated* because they are theory-driven and introduce additional assumptions into the model structure. Among these approaches, we investigate the plausibility of the Galí, Smets and Wouters (2011) labour market structure with labour market markup and the search and matching (S&M) concept proposed by Mortensen and Pissarides (1994).

[2] An outline of the derivation is given in Appendix A.1.

### 3.1 Calvo Wage Parameter Change

Bayesian estimation of the Calvo wage parameter $\xi_L$ (see Figure A1) suggests that the rigidity of nominal wages should be set higher than the current value of 0.8 (five quarters) or alternatively we should try to find another way of increasing the rigidity, because values higher than 0.8 seem to be implausible. This experiment (labelled *calvo*) does not yield any improvement in the unemployment forecast and only shows how much the rigidity has to be adjusted.

### 3.2 Data Change

As the second exercise (labelled *data change*), the time series of average nominal wages was replaced by the series of average nominal wages per hour. Since the average nominal wage per hour is not published, we calculate it as wages and salaries divided by hours worked. We also replace employment with hours worked. Hence, the volume of wages and salaries is kept, only its components are changed (see Figure A2).

### 3.3 Observing Unemployment

The next exercise is the replacement of employment by unemployment (exercise *obs unempl*) as the observed variable (see Figure A3). The following equations are incorporated into the model:

$$u_t = \frac{1}{ell_t}$$
$$obs_t^{\text{UNEMPL}} = \log(u_t) + \omega_t^{\text{UNEMPL}}.$$

We found that the simplest approximation is the most effective, i.e. it delivers the smallest prediction errors. Alternatives include: the incorporation of equations $u_t = \frac{L_t}{ell_t}$ and $obs_t^{\text{UNEMPL}} = \log(u_t) + \omega_t^{\text{UNEMPL}}$ and modelling labour force $L_t$ as exogenous, or the incorporation of $u_t = \frac{L_t - ell_t}{L_t}$ and $obs_t^{\text{UNEMPL}} = u_t + \omega_t^{\text{UNEMPL}}$, and setting employment and labour force as observables. It is also possible to set employment with lag $ell_{t-j}$ in equation $u_t = \frac{L_t}{ell_{t-j}}$, or set weights on these lags. Furthermore, it is possible to test different ways of linking, i.e. it is possible to link the trend and the cycle and test the effects of different smoothing. All these options give the same or higher prediction errors, so they are not tested on subsequent concepts.

#### *3.3.1 Reduction of Employment Elasticity*

We modified the *obs unempl* exercise by imposing elasticity on employment (exercise *obs unempl-elastic*). In equation

$$u_t = \frac{1}{ell_t^{1/3}}$$

we set the weight of employment equal to $\frac{1}{3}$. This idea is motivated by the variances of labour market observables (see Figure A3). We observe, for example, that the unemployment gap is about one third of the size of the lagged GDP gap (t-2). This modification leads to an improvement in the prediction of unemployment, but at the same time the predictions of the rest of the observables deteriorate, especially the predictions of interest rates, consumption and wages.

### 3.4 Unemployment Based on Output Gap

In this exercise (we shall refer to it as the *gdp gap* modification) we incorporate into the model a link between unemployment and the GDP gap and make unemployment an observed variable (again motivated by Figure A3).

$$\log\left(\frac{u_t}{u_t^{\text{trend}}}\right) = -\frac{1}{5}y_{t-2}^{\text{gap}}$$

The puzzle is how to calibrate the parameter. In the above case, we chose a parameter value that delivers a reasonable variation of the unemployment prediction yet does not worsen the prediction of the other observables too much. Another possibility is to link unemployment directly to foreign demand. In that case, in-sample simulations are even better, but the development of unemployment lacks a structural background (story) because it is caused by a foreign demand shock, which is exogenous. Therefore, this option is basically equivalent to determining unemployment outside the model.

### 3.5 Galí, Smets and Wouters Model (2011)

The idea of Galí et al. (2011) (GSW henceforth) is to link unemployment and labour market markup (this exercise is referred to as *Markup*)[3]:

$$markup^L = u_t^{\varphi}.$$

An equation defining labour supply is incorporated into the model (with labour force $LF_t$ as a new variable).

$$\frac{\kappa LF_t^{\varphi}}{\lambda_t} = (1-\tau^W)w_t.$$

The labour market markup is proportionally linked to unemployment, because monopolistically competitive households are able to bargain for higher wages than they would receive in a situation of perfect competition. There is also a factor that enables us to control for wealth effects in the model. Unemployment is not included in the monetary policy rule, because the CNB implements a pure regime of inflation targeting.

#### *3.5.1 Markup with Reduction of Employment Elasticity*

Here, a modification of *Markup* with employment elasticity is tested (we shall refer to it as *Markup-elastic*). Into equation

$$\frac{\kappa L_t^{\varphi}}{\lambda_t} = (1-\tau^W)w_t$$

we substituted $L_t = u_t ell_t$ and added elasticity with respect to employment (as in *obs unempl-elastic*) and obtained

$$\frac{\kappa(u_t ell_t^{1/3})^{\varphi}}{\lambda_t} = (1-\tau^W)w_t.$$

This modification was also tested on the original Galí et al. (2011) model. An in-sample simulation (see Appendix A.10) shows that the greatest improvement is achieved for the unemployment variable, while the remaining variables are forecasted with roughly similar accuracy.

[3] An outline of the derivation is given in Appendix A.4

#### *3.5.2 Markup with Zero Employment Elasticity*

This option is an extreme case of *Markup-elastic* (we shall refer to it as *Markup-inelastic*). We get

$$\frac{\kappa(u_t)^{\varphi}}{\lambda_t} = (1-\tau^W)w_t.$$

The impulse response analysis shows how the calibration of the elasticity parameter changes the model's behaviour. We can see that the direction of the impulse responses does not change. What changes is the magnitude of the impulse responses, especially for unemployment and wages.

### 3.6 Search and Matching Frictions

The S&M concept, as introduced by Mortensen and Pissarides (1994), is based on the assumption that the process of searching for a suitable worker to fill a vacancy generates costs for firms and this constitutes labour market friction. Unlike previous approaches to labour market modelling, the S&M concept covers the development of employment (the extensive margin of labour supply) as well as hours worked (the intensive margin of labour supply). In the model, the process of job search is formally outsourced to an employment agency. This representative agent links vacant jobs to unemployed workers via a process described by the matching function

$$m_t = \sigma_m u_t^{\xi} v_t^{1-\xi},$$

where $m_t$ is the number of newly created job-worker pairs, $u_t$ is a measure of unemployment and $v_t$ is a measure of job vacancies. $\sigma_m$ and $\xi$ are parameters of the matching process. The surplus generated by the newly created job-worker pairs is usually distributed based on Nash bargaining. In Nash bargaining, wages and hours worked are set in a way that maximizes the common surplus of both the firm and the worker and this surplus is divided according to the bargaining power of the two sides of the agreement. The corresponding optimization problem can be written as

$$\max_{W_t,h_t}(\Delta_t(W_t))^{\eta}(J_t(W_t))^{1-\eta},$$

where $\Delta_t$ is the value of the job for the employee, $J_t$ is the value of the filled vacancy for the firm, $W_t$ stands for the nominal wage and $h_t$ are the hours worked. $\eta$ is the parameter that describes the bargaining power of the employee. The remaining crucial equation of the S&M concept governs the decision of the firms about the number of vacancies posted. The first-order condition equates the costs of vacancy posting $\kappa$ and the discounted value of the filled vacancy weighted by the probability of a successful match,

$$\kappa = q_t E_t\{\beta_{t,t+1}[\gamma J_{t+1}(W_t) + (1-\gamma)J_{t+1}(W_{t+1}^*)]\},$$

where $q_t$ is the probability of finding a suitable worker for the posted vacancy, $\beta_{t,t+1}$ is the discount factor, $\gamma$ is the Calvo parameter and $W_t^*$ is the newly bargained wage. When only a fraction $(1-\gamma)$ of existing workers are allowed to renegotiate their wages each period and the remaining fraction $\gamma$ are remunerated by the average wage of the last period, the average wage develops according to

$$W_t = \gamma W_{t-1} + (1-\gamma)W_t^*.$$

#### *3.6.1 Christoffel and Kuester Model (2008)*

This exercise follows Christoffel and Kuester (2008). The authors compare two types of wage bargaining within the S&M concept. Efficient Nash bargaining (*S&M-Nash*) is more common in the literature and is easier to implement. On the other hand, right-to-manage (*S&M-Manage*) bargaining may be closer to the actual reality of labour market mechanics.

In the case of *S&M-Nash*, firms negotiate with workers about wages and hours worked at the same time, and the resulting situation is Pareto optimal. Hours worked are set so as to equate the marginal value product of labour and the workers' marginal rate of substitution between leisure and consumption. Wages therefore do not directly influence production and thus they do not play a direct role in influencing the marginal costs of price-setting firms. In fact, wages only affect the distribution of the common surplus generated by the filled job position between the firm and the worker.

In the case of *S&M-Manage*, firms negotiate with workers only about wages. After the wage bargaining is finished, hours worked are set by the firms so as to maximize profits. The first-order condition for hours worked equates the marginal value product of labour and the real hourly wage

$$x_t^L \alpha z_t h_t^{\alpha-1} = W_t,$$

where $x_t^L$ is the wholesale price of intermediate production and $\alpha z_t h^{\alpha-1}$ is the marginal product of labour. Since the wholesale sector is assumed to be competitive, $x_t^L$ can be interpreted as marginal costs $mc_t$

$$mc_t = \frac{1}{\alpha}\frac{W_t h_t}{z_t h_t^{\alpha}}.$$

This equation implies that higher wages induce higher inflation and that stickiness in wages translates into stickiness of marginal costs. This stickiness also translates into a muted response of inflation to shocks via the New Keynesian Phillips curve. Under *S&M-Manage*, wages and anything affecting the wage-setting process thereby have a direct effect on inflation.

#### *3.6.2 Christiano, Trabandt and Walentin Model (2011)*

The final S&M exercise employs the model concept of Christiano et al. (2011) (we shall refer to it as *CTW*). *CTW* extend the classical S&M concept into an elaborate model of the labour market consisting of approximately 80 equations, which makes their model structure difficult to implement. The probability of finding a job increases with search effort, and imperfect risk sharing among individuals is a consequence of the non-observability of effort. A key feature of this model is that while there are wage-setting frictions, these do not have a direct impact on ongoing worker-employer relations as long as they are mutually beneficial. However, wage-setting frictions have an impact on the effort of an employer in recruiting new employees.

There are two main differences between *CTW* labour market modelling and the S&M concepts described above. First, *CTW* work with Taylor-type wage frictions, while Calvo frictions are commonly assumed in the literature. Second, *CTW* allow for endogenous separation of employees from their jobs, while exogenous separation is common in the literature.

The *CTW* concept works with the representative agent of an employment agency and assumes that each employment agency retains a large number of workers. At the beginning of each period a fraction of workers are randomly selected to depart from the agency and go into unemployment, i.e. exogenous separation takes place. Also, a number of new workers arrive from unemployment in proportion to the number of vacancies posted by the agency in the previous period as a result of the S&M process. After departure and new arrivals occur, the nominal wage rate is set. Then idiosyncratic shocks to workers' productivities are realized and endogenous separation decisions are made. The nominal wage paid to an individual worker is determined by Nash bargaining, which occurs once every $N$ periods. Each employment agency is permanently allocated to one of $N$ different cohorts. The cohorts are differentiated according to the period in which they renegotiate their wage. Since there is an equal number of agencies in each cohort, $1/N$ of the agencies bargain in each period. This setup constitutes Taylor-type wage rigidity. Finally, the intensity of the labour effort is determined efficiently by equating the worker's marginal cost to the agency's marginal benefit.

## 4. Tests on Data

To assess the plausibility of the alternative labour market concepts, standard tests were performed on historical data. The in-sample simulations were followed by shock decompositions and impulse response analysis.

### 4.1 In-sample Simulations

In this subsection we first evaluate the predictive ability for unemployment of the alternative model specifications using the prediction errors of in-sample simulations. Next, we consider the change in the overall predictive ability across all observable variables compared to the baseline model. Finally, we take into consideration the extent of the required model change.

In order to be able to evaluate the change in the overall predictive ability caused by the incorporation of a labour market concept into the baseline model, we decided to introduce a formal criterion defined as the sum of the relative changes in the RMSFE[4] of particular observables. We have 13 observables in the baseline model. Let us denote as $RMSFE_i^{BL}$ the forecast error of the $i$-th observable in the baseline model and $RMSFE_i^{LM}$ the forecast error of the $i$-th observable in the alternative specification with a more elaborate labour market. The model selection criterion is then defined as

$$\sum_{i=1}^{13} \frac{RMSFE_i^{LM} - RMSFE_i^{BL}}{RMSFE_i^{BL}} \cdot 100 \ \ [\%].$$

The lower the negative value of the selection criterion, the bigger the improvement in the overall predictive ability caused by the incorporation of the given labour market concept into the baseline model.

Two alternative selection criteria are calculated and reported in Tables A1 and A2 – including and excluding unemployment. The alternative that does not take into account the observed time series of unemployment is useful for distinguishing the impact of the particular labour market extension on the overall predictive ability of the baseline set of observables. However, this alternative selection criterion has one serious drawback – it does not take into account the qualitative difference between the alternative models that are able to predict unemployment and those that are not. Neither does

[4] Root mean squared forecast error. The baseline forecasting horizon is eight quarters ahead. This value is the average forecasting horizon, because it ranges from six to ten quarters.

this criterion take into account the differing reliability of the forecast of unemployment produced by alternative model specifications. Because of these shortcomings of the first selection criterion, we also present the values of a modified selection criterion that includes a relative improvement of the forecast error of unemployment with respect to the *obs unempl* model specification. The *obs unempl* specification was chosen as a benchmark because it is the simplest model specification that contains unemployment and is, therefore, closest to the baseline model structure.

From the point of view of the prediction of unemployment, the following concepts seem best: *obs unempl-elastic*, *Markup-inelastic*, *Markup-elastic*, *S&M-Manage*, *CTW* and *gdp gap* (see Figure A7 of the unemployment in-sample simulation). These concepts achieve the lowest prediction errors for unemployment, but only *gdp gap*, *Markup-inelastic*, *Markup-elastic* and *S&M-Manage* achieve comparable or better results in their prediction of the remaining observables (see Table A1 of the in-sample simulation results).

According to the selection criterion that takes into account unemployment, we found that the model concept *Markup-inelastic* is the most successful. However, the assumption of zero employment elasticity is rather extreme. In theory, the wage markup should be related to the labour force, which is in turn largely influenced by the development of employment. Nevertheless, some reduction of employment elasticity is necessary in order to obtain reasonable prediction of unemployment (see row *UR* of *Markup* in Table A1.) Also, the advantage of further employment elasticity reduction seems rather modest in comparison with the *Markup-elastic* alternative. Therefore, we chose the *Markup-elastic* concept as the one that is to be preferred.

In general, the models with alternative labour market concepts do not significantly differ from the baseline model in their ability to predict CPI inflation. This is mainly because the purpose of DSGE models is to get inflation back to the target.[5] The alternative concepts tend to forecast nominal wage growth more precisely (as is evident from Table A2) because they incorporate more (actually observed) rigidity in wages (see, for example, Figure A9). Given the relatively similar accuracy in predicting inflation, the exchange rate is bound to be predicted more precisely, because nominal wages and foreign prices (the exchange rate multiplied by on-future-fixed[6] foreign prices in a foreign currency) are the only sources of inflationary pressures. Therefore, the main advantage of the extended labour market concepts in relation to inflation lies in improved forecasts of wages and the exchange rate, which leads to a more realistic composition of inflation pressures.

Most of the labour market concepts are not successful in predicting consumption (*gdp gap* is the most apparent case). This can be explained by the relatively low cyclicality of consumption (see the result of Brůha and Polanský (2013) in Appendix A.5). If the model change consists in observing cyclical unemployment, it naturally leads to an improvement in the prediction of very cyclical variables such as exports and GDP, but the prediction of consumption must logically worsen.

Another issue is how predictive ability is influenced by the choice of forecasting horizon. Table A1 also contains the in-sample simulation results for the *S&M-Manage* and *Markup-elastic* concepts for six and ten quarters ahead. The predictive ability tends to decrease when the forecasting horizon is shortened.

[5] Another justification is that DSGE models are intended not to capture short-run fluctuations in CPI inflation, but to capture the dynamics of CPI inflation in the medium term (see, for example, Figure A8).
[6] The outlook of foreign variables is exogenous to the forecast. It is based on the Consensus Forecast outlook.

Table A2 shows the predictive ability of model modifications for the crisis period (2010Q1 to 2015Q1). It confirms the above conclusion that the concepts *Markup-inelastic* and *Markup-elastic* are preferred when considering in-sample simulations statistics criterion including unemployment.

According to the selection criterion, the reliability of the model forecast of the *S&M-Manage* labour market concept worsened significantly in comparison to the other alternatives in the crisis period. However, to a large extent the comparative deterioration is given by a differing forecast path of the policy interest rate (*IR*) as compared to the historical values. This is not necessarily a problem per se. The setting of policy interest rates would probably have been different had this model concept been used in the past. Therefore, the *S&M-Manage* concept can be considered relatively successful. In comparison to the *Markup-elastic* concept, the *S&M-Manage* concept is slightly less successful in forecasting unemployment and it also requires significant changes to the baseline model (the addition of 20 new equations to make 80 equations overall).

Therefore, the *Markup-elastic* and *gdp gap* concepts are preferred when considering in-sample simulation statistics together with the extent of model change.

## 4.2 Shock Decomposition

Shock decompositions for unemployment are included in Appendix A.7. The main driving forces of unemployment in the period of the 2008–2009 crisis and the subsequent recovery, as identified by the individual labour market concepts, are discussed in this section.

According to the *obs unempl* concept, technological shocks and, with a short delay, also labour market shocks contributed strongly to the rise in unemployment during the crisis. On the other hand, government shocks and consumption habits acted in the opposite direction. The *obs unempl-elastic* alternative does not change the story very much. The downward effect of habit shocks on unemployment appears even before the crisis and therefore helps explain the decline in unemployment, and labour market shocks push the unemployment rate higher several quarters later. In both concepts, the role of labour market shocks is considerable but certainly not dominant.

The *gdp gap* concept tells a similar story with a few differences. The evolution of technological shocks and habit shocks drove unemployment down in the period of economic boom before the crisis. Labour market shocks exerted slight downward pressure on unemployment during the period of 2008–2010. The rise in unemployment during the crisis is explained mainly by the fading out of the positive influence of technological and habit shocks. Government shocks pushed unemployment persistently up over the whole horizon, but during the crisis their influence abated slightly. Also, in comparison with the *obs unempl* and *obs unempl-elastic* concepts, the role of technological and habit shocks after the crisis is reversed. The role of labour market shocks is virtually negligible in the *gdp gap* concept.

The *Markup-elastic* concept again shows a prominent role of technological shocks, but at the same time it attributes equal importance to labour market shocks. During the boom, unemployment was driven down by technological shocks, while the remaining shocks acted in the opposite direction, with labour market shocks being the most distinct. The habit shock pushed unemployment up before the crisis as well. During the crisis it was mainly technological shocks that led to the increase in unemployment, while labour market shocks and, to a small extent, also habit and Euler shocks acted against the increase.

The *S&M-Manage* concept explains the historical development of unemployment in terms of exogenous shocks very similarly to the *Markup* concept. The main difference is the longer-lasting effects of labour market shocks, which partially explain the rise in unemployment during the crisis, together with the fading downward effects of technological shocks.

According to the *CTW* concept, the decline in unemployment in the period of economic boom is explained by both technological and labour market shocks acting in the same direction while being aided by less substantial government shocks and partially offset by investment-specific shocks. During the crisis, the downward effects of labour market shocks and government shocks weakened while the effects of technological shocks pushed unemployment up rather forcefully.

The historical shock decompositions show a similar structural story for the *obs unempl*, *obs unempl-elastic* and *gdp gap* concepts and for the *Markup-elastic* and *S&M-Manage* concepts. Simpler approaches to labour market modelling explain the development of unemployment with the use of habit shocks to a relatively large and implausible extent. More elaborate *Markup-elastic* and S&M concepts attribute much greater importance to labour market shocks when explaining the development of unemployment. The *CTW* concept identifies relatively small downward pressure from technological shocks on unemployment in the 2006–2007 boom period. Also, the persistent downward pressure from labour market shocks exerted on unemployment since 2000 seems rather implausible. Therefore, it is the shock decompositions produced by the *Markup-elastic* and *S&M-Manage* concepts that we find the most intuitive.

### 4.3 Impulse Responses

An increased value of the Calvo wage parameter in the Calvo specification *calvo* implies higher rigidity of nominal wages and higher volatility of unemployment. After a positive labour-augmenting technology shock, the exchange rate depreciates. The rest of the simple modifications of the baseline g3 leave the impulse responses unchanged, except for the reaction of employment (unemployment). As shown in the figures in Appendix A.8, the *obs unempl-elastic* and *gdp gap* concepts reduce unemployment volatility.

The more sophisticated concepts must be analysed more deeply. The reaction of the more sophisticated models to monetary policy shocks is standard, varying only in intensity. It is worth mentioning that alternative models show a weaker reaction of nominal wages and unemployment than the standard g3 model. This actually implies a lower volatility of unemployment in the in-sample simulations.

The reaction of the more sophisticated models to a labour-augmenting technology shock is rather intuitive. A positive shock should imply lower-than-steady-state inflation and higher-than-steady-state output. What seems to be interesting is the depreciated exchange rate in the case of the *Markup* and *S&M-Manage* models. The reason for this lies in lower net exports, because labour market rigidities for the intermediate sector must be imported.

The *S&M-Manage* model seems to react to a foreign demand shock in the opposite direction to the other models. The explanation lies in lower wages being outweighed by exchange rate appreciation.

Higher foreign interest rates lead to depreciation, inflation and higher domestic interest rates (the UIP condition). The reaction of nominal wages and unemployment is rather moderate, which is more in line with reality.

Compared to g3, the reaction of the models to a debt-elastic premium shock differs mainly in wages and unemployment. The response is less volatile, which is also more intuitive.

For *Markup-elastic* and *S&M-Manage*, habit shocks imply the intuitive reaction of nominal wages, which grow after such a shock occurs. This obviously leads to better results in the in-sample simulations. On the other hand, the reaction of inflation and interest rates in the *S&M-Manage* model is less intuitive.

The *S&M-Manage* model seems to react to a positive wage cost-push shock less intuitively in the case of inflation and interest rates. The change of behaviour can be explained by the fact that the incorporation of the labour market increases the overall model rigidity (as we can see in the data). Thus, the reaction of the exchange rate has to be stronger so as to get inflation back to the target.

It is possible to adjust the impulse responses (and bring them closer to their original shape) by changing the labour market markup, adjusting labour-augmenting technology rigidity or changing the forward-lookingness of the UIP condition. The alteration of these parameters does not have a significant effect on the quality of the predictions.

# 5. Monetary Policy Implications

When we focus on the in-sample simulations during the crisis period in more detail, we see that the nominal exchange rate is more depreciated and nominal wages are lower in models with a more elaborate labour market than the g3 model (see Appendix A.9). Our explanation is the following.

In the current version of the g3 model, an infinite supply of labour is assumed to be available on the labour market. This means that employers (intermediate goods-producing firms) can adjust the number of employees at will, with no restrictions on the timing or extent of the adjustment. Therefore, even if rigid nominal wages are assumed, employers can reduce wage costs in a situation of unsatisfactory demand.

In models with a more elaborate labour market structure, employers must carefully consider the optimal number of newly hired or dismissed employees. Additional rigidities introduced into the model structure (e.g. a search and matching mechanism) make it more difficult and costly to adjust the number of employees. This is the main reason why a less vigorous increase in the wages was foreseen by the models with explicit labour markets in the crisis period as compared to the baseline g3 model. The lower expected wage growth translated into lower predicted growth of consumption. This may partially explain why the models with more elaborate labour markets fared worse than the baseline model in forecasting consumption during the crisis period.

If true, this finding would have an interesting monetary policy implication. The Czech National Bank started using the koruna exchange rate as an additional monetary policy instrument in autumn 2013 when interest rates had already reached the zero lower bound and further easing of monetary policy was necessary. Models with elaborate labour markets would probably have identified an even higher need for a weaker exchange rate in order to deliver the desired inflationary pressures than the g3 model did.

## 6. Summary

Various approaches to labour market modelling were considered in this paper, ranging from simple approaches to elaborate search and matching concepts. We identified three promising approaches that are able to predict unemployment with a reasonable error and at the same time improve the overall predictive ability of the whole model. The simplest one links unemployment and the GDP gap. The other two concepts are the relatively straightforward approach of Galí et al. (2011), which links unemployment to the labour market markup, and the search and matching concept with right-to-manage bargaining of Christoffel and Kuester (2008). The preferred type of modification is the concept of Galí et al. (2011), which gives more reliable forecasts overall and at the same time requires model changes of a reasonable extent. The Galí et al. (2011) approach leads to a cumulative improvement of the predictive power (as measured by the in-sample simulations) across all the observables of approximately 20 (40) per cent in the period 2002Q1-2015Q1 (2010Q1-2015Q1) compared with the baseline model. A necessary condition for obtaining such a result is to reduce employment elasticity. This elasticity reduction is supported by the fact that the variance of the unemployment gap is about one third of that of the lagged GDP gap. Shock decompositions tell a relatively consistent story in showing which shocks are fundamental for explaining unemployment (technology, habits, government and labour market shocks).

As a practical result, we saw that the models with simple labour markets tend to forecast higher nominal wage growth and lower exchange rate depreciation during the crisis. This has an interesting monetary policy implication, because the Czech National Bank started using the koruna exchange rate as an additional monetary policy instrument in autumn 2013, when interest rates had already reached the zero lower bound and further easing of monetary policy was necessary. In order to deliver the desired inflationary pressures, the Czech National Bank intervened in the foreign exchange market and induced a depreciation of its currency. Models with elaborate labour markets would probably have identified an even higher need for a weaker exchange rate than the baseline g3 model did.

## References


ANDRLE, M., T. HLÉDIK, O. KAMENÍK, AND J. VLČEK (2009): "Implementing the New Structural Model of the Czech National Bank." Working Papers 2009/2, Czech National Bank, Research Department.

BABECKÝ, J., K. DYBCZAK, AND K. GALUŠČÁK (2008): "Survey on Wage and Price Formation of Czech Firms." Working Papers 2008/12, Czech National Bank, Research Department.

BABECKÝ, J., K. GALUŠČÁK, AND L. LÍZAL (2011): "Firm-Level Labour Demand: Adjustment in Good Times and During the Crisis." Working Papers 2011/15, Czech National Bank, Research Department.

BIČÁKOVÁ, A. (2006): "Market vs. Institutions: The Trade-off Between Unemployment and Wage Inequality Revisited." Economics Working Papers ECO2006/31, European University Institute.

BLANCHARD, O. (2008): "A new method to estimate time variation in the NAIRU - comments." *Conference Series ; [Proceedings],* 53.

BLANCHARD, O. AND J. GALÍ (2010): "Labor Markets and Monetary Policy: A New Keynesian Model with Unemployment." *American Economic Journal: Macroeconomics,* 2(2):1–30.

BLANCHARD, O. AND J. GALÍ (2007): "Real Wage Rigidities and the New Keynesian Model." *Journal of Money, Credit and Banking,* 39(s1):35–65.

BRŮHA, J. (2011): "An Empirical Small Labor Market Model for the Czech Economy." *Czech Journal of Economics and Finance (Finance a uver),* 61(5):434–449.

BRŮHA, J. AND J. POLANSKÝ (2013): "Empirical analysis of labour markets: An International comparison." Technical report.

BRŮHA, J., B. PIERLUIGI, AND R. SERAFINI (2011): "Euro area labour markets: different reaction to shocks?." Working Paper Series 1284, European Central Bank.

CHRISTIANO, L. J., M. TRABANDT, AND K. WALENTIN (2011): "Introducing financial frictions and unemployment into a small open economy model." *Journal of Economic Dynamics and Control,* 35(12):1999–2041.

CHRISTOFFEL, K. AND K. KUESTER (2008): "Resuscitating the wage channel in models with unemployment fluctuations." *Journal of Monetary Economics,* 55(5):865–887.

CHRISTOFFEL, K., J. COSTAIN, G. DE WALQUE, K. KUESTER, T. LINZERT, S. MILLARD, AND O. PIERRARD (2009): "Inflation dynamics with labour market matching: assessing alternative specifications." Working Papers 09-6, Federal Reserve Bank of Philadelphia.

DE WALQUE, G., O. PIERRARD, H. SNEESSENS, AND R. WOUTERS (2009): "Sequential bargaining in a New Keynesian model with frictional unemployment and staggered wage negotiation." Working Paper Research 157, National Bank of Belgium.

ERCEG, C. J., D. W. HENDERSON, AND A. T. LEVIN (2000): "Optimal monetary policy with staggered wage and price contracts." *Journal of Monetary Economics,* 46(2):281–313.

FAIA, E. (2008): "Optimal monetary policy rules with labor market frictions." *Journal of Economic Dynamics and Control,* 32(5):1600–1621.

FAIA, E. (2009): "Ramsey monetary policy with labor market frictions." *Journal of Monetary Economics,* 56(4):570–581.

FARMER, R. (2010): *Expectations, Employment and Prices,* number 9780195397901 of *OUP Catalogue.* Oxford University Press.

GALÍ, J., F. SMETS, AND R. WOUTERS (2011): "Unemployment in an estimated new Keynesian model." Economics Working Papers 1266, Department of Economics and Business, Universitat Pompeu Fabra.

GALUŠČÁK, K. AND D. MÜNICH (2007): "Structural and Cyclical Unemployment: What Can Be Derived from the Matching Function? (in English)." *Czech Journal of Economics and Finance (Finance a uver),* 57(3-4):102–125.

GALUŠČÁK, K. AND J. PAVEL (2012): "Taxes and Benefits: Work Incentive Effects of Policies." *Czech Journal of Economics and Finance (Finance a uver),* 62(1):27–43.

GERTLER, M., L. SALA, AND A. TRIGARI (2008): "An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining." Working Papers 341, IGIER (Innocenzo Gasparini Institute for Economic Research), Bocconi University.

HALL, R. E. (2005): "Employment Fluctuations with Equilibrium Wage Stickiness." *American Economic Review,* 95(1):50–65.

HALL, R. E. (2006): *Job Loss, Job Finding and Unemployment in the U.S. Economy over the Past 50 Years.* In *NBER Macroeconomics Annual 2005, Volume 20*NBER Chapters, *pages 101–166.* National Bureau of Economic Research, Inc.

HALL, R. E. (2005): "Employment Efficiency and Sticky Wages: Evidence from Flows in the Labor Market." NBER Working Papers 11183, National Bureau of Economic Research, Inc.

HURNÍK, J. AND D. NAVRÁTIL (2005): "Labor-Market Performance and Macroeconomic Policy: Time-Varying NAIRU in the Czech Republic (in English)." *Czech Journal of Economics and Finance (Finance a uver),* 55(1-2):25–40.

MORTENSEN, D. T. AND C. A. PISSARIDES (1994): "Job Creation and Job Destruction in the Theory of Unemployment." *Review of Economic Studies,* 61(3):397–415.

PROIETTI, T. AND A. MUSSO (2007): "Growth accounting for the euro area: a structural approach." Working Paper Series 0804, European Central Bank.

SHIMER, R. (2007): "Reassessing the Ins and Outs of Unemployment." NBER Working Papers 13421, National Bureau of Economic Research, Inc.

SMETS, F. AND R. WOUTERS (2007): "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review,* 97(3):586–606.

SMETS, F. AND R. WOUTERS (2003): "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association,* 1(5):1123–1175.

THOMAS, C. (2008): "Search and matching frictions and optimal monetary policy." *Journal of Monetary Economics,* 55(5):936–956.

TRIGARI, A. (2009): "Equilibrium Unemployment, Job Flows, and Inflation Dynamics." *Journal of Money, Credit and Banking,* 41(1):1–33.

WALSH, C. E. (2005): "Labor Market Search, Sticky Prices, and Interest Rate Policies." *Review of Economic Dynamics,* 8(4):829–849.

# Appendix A:

## A.1 Derivation of g3 Labour Market

The household's optimization problem from the point of view of the labour market[7] is to maximize its utility function with respect to hours worked $L_t$[8], consumption $C_t$ and nominal wages per hour $W_t$.

$$\max_{L_t(h),W_t(h)} \mathscr{L}_s(h) = E_t \sum_{s=t}^{\infty} \beta^{s-t} \{\log \frac{C_s - \chi H_s}{1-\chi} - \kappa a_s^L L_s(h)$$
$$-\Lambda_s[\cdots + P_s^C C_s(h) \ldots - (1-\tau^W) W_s(h) L_s(h)]\}.$$

The maximization of utility with respect to hours worked implies

$$-\kappa a_t^L - \Lambda_t[-(1-\tau^W)W_t(h)] = 0, \tag{A.1}$$

i.e. the marginal utility from one hour of leisure time is equivalent to the nominal wage per hour after taxation. $\kappa$ is the scale of hours in utility, $a_t^L$ is the willingness to work technology, $P_t^c$ is the consumption price and $H_t$ is habit.

In the g3 model, the above equation is represented by a condition which equalizes the marginal rate of substitution between leisure time and consumption with the relative price of labour (relative to consumption prices). Thus, the maximization of utility from consumption implies

$$\frac{1}{C_t - \chi H_t} - \Lambda_t P_t^C = 0. \tag{A.2}$$

The resulting condition[9] takes the form

$$\frac{\kappa a_t^L}{\frac{1}{C_t - \chi H_t}} = \frac{(1-\tau^W)W_t}{P_t^C} \text{ or } \frac{\kappa a_t^L}{\Lambda_t} = (1-\tau^W)W_t. \tag{A.3}$$

After stationarization by $a_t^L P_t^Y Z_t$, where $P_t^Y$ is the price in the intermediate production sector and $Z_t$ is aggregate technology, we get

$$\frac{\kappa}{P_t^Y Z_t \Lambda_t} = (1-\tau^W)\frac{W_t}{a_t^L P_t^Y Z_t} \text{ and } \frac{\kappa}{\lambda_t} = (1-\tau^W)w_t. \tag{A.4}$$

If monopolistic competition is assumed on the labour market (with fully flexible wages), the resulting wage is increased by a markup[10] stemming from monopolistic competition ($markup^L = \frac{\varepsilon^W}{1-\varepsilon^W}$) and thus

$$\frac{\kappa}{\lambda_t} markup^L = (1-\tau^W)w_t. \tag{A.5}$$

[7] Assume now that the labour market is perfectly competitive, i.e. demand for each household's labour is perfectly elastic, and that there is no wage rigidity.

[8] In the original derivation, leisure time is considered, i.e. the utility function has the form $\log \frac{C_s - \chi H_s}{1-\chi} + \kappa a_s^L(1 - L_s(h))$. The consequences of such a definition are equivalent to the notation $\log \frac{C_s - \chi H_s}{1-\chi} - \kappa a_s^L L_s(h)$. For the purposes of this paper it is more convenient to choose this new form.

[9] It makes no difference which two conditions, whether (A.1) and (A.2), or (A.2) and (A.3), represent this optimization exercise.

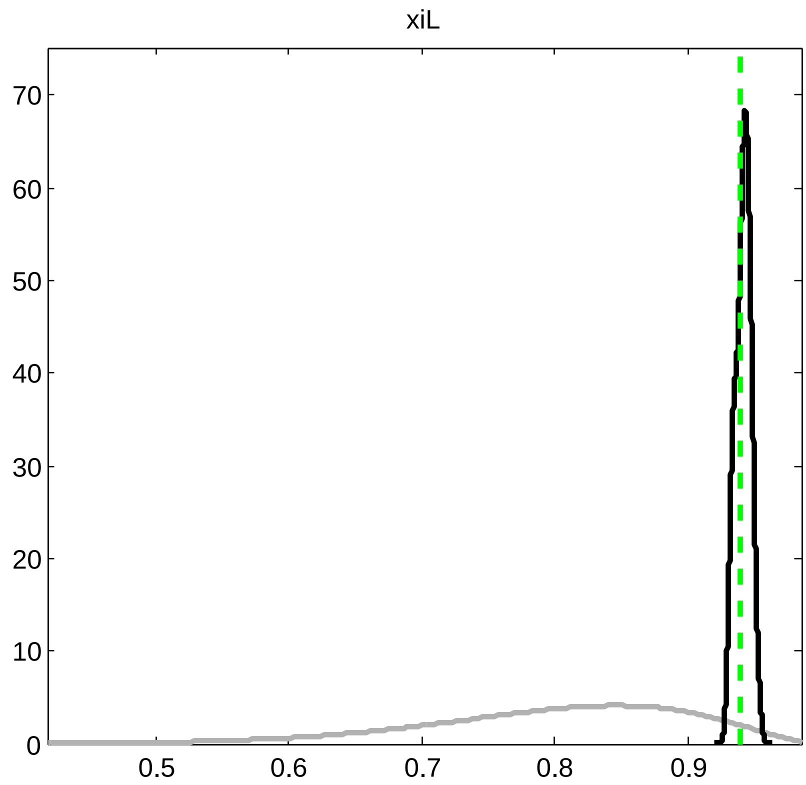
[10] The wage Phillips curve can be expressed using real wage costs, i.e. $markup_t^L = \frac{1}{rmc_t^W}$.

If wage rigidity à la Calvo is further assumed, the markup is time-varying ($markup_t^L = \frac{(1-\tau^W)w_t}{\frac{\kappa}{\lambda_t}}$) and wage inflation is given by

$$\log\left(\frac{\pi_t^w}{\pi_{t-1}^w}\right) = \beta \log\left(\frac{\pi_{t+1}^w}{\pi_t^w}\right) - \frac{(1-\beta\xi^L)(1-\xi^L)}{\xi^L} \log\left(\frac{markup_t^L}{markup^L}\right) + \varepsilon_t^{labor}. \tag{A.6}$$

## A.2 Calvo Wage Parameter Estimation

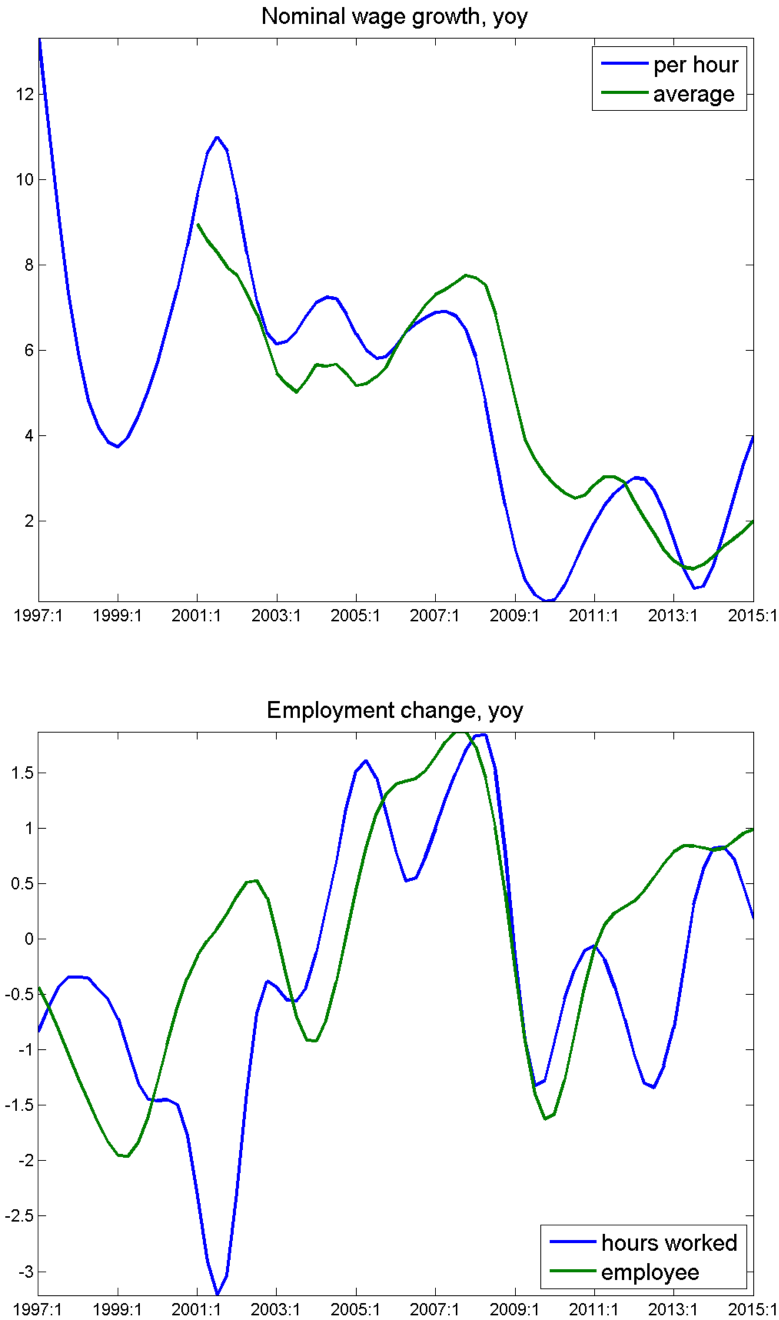
***Figure A1: Bayesian Estimation of the Calvo Wage Parameter***




***Notes***: The figure shows the prior (grey line) and posterior (black line) density of the Calvo wage parameter $\xi_L$ together with its posterior mode (dashed green line). The posterior mean is very high (0.94), which suggests that nominal wages are very rigid.

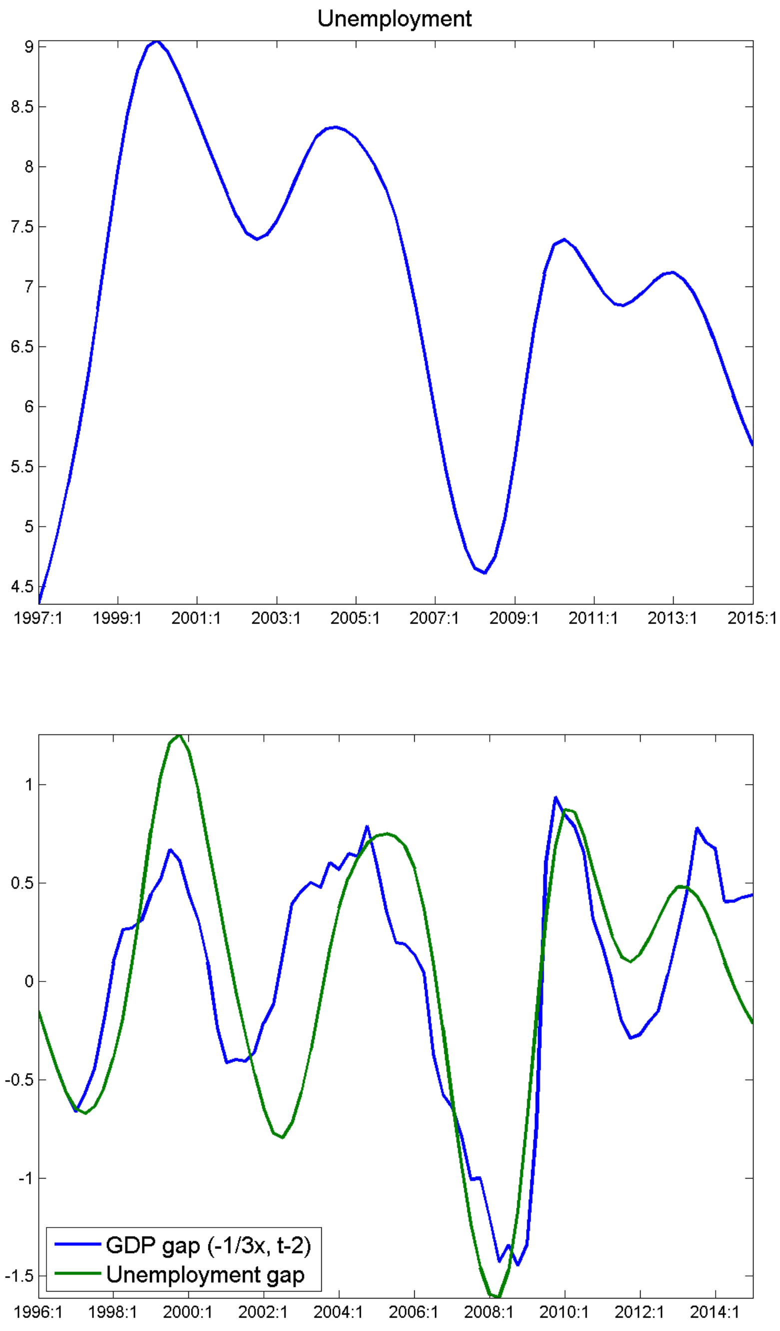
## A.3 Czech Labour Market Data

### *Figure A2: Labour Market Variables*




***Notes***: The top figure compares annual hourly nominal wage growth (blue) with annual average nominal wage growth (green) in per cent. The bottom figure compares annual employment changes in per cent as captured by hours worked (blue) with the number of employed people (green). The hourly nominal wage was calculated as total wages and salaries divided by hours worked. Therefore, the total volume of wages is the same in both alternatives, only the structure differs.

***Figure A3: Unemployment, the GDP Gap and the Unemployment Gap***




***Notes***: The top figure depicts the development of the unemployment rate in per cent. The bottom figure compares the unemployment rate gap in percentage points (green) and the real GDP gap in per cent multiplied by $-\frac{1}{3}$ and lagged by two quarters (blue). We can see that the unemployment gap is roughly one third of the size of the lagged GDP gap.

### A.4 The Incorporation of *Markup* into g3

Galí allows the distribution of the disutility of labour among individuals through parameter $\varphi$

$$\max_{L_t(h),W_t(h)} \mathscr{L}_s(h) = E_t \sum_{s=t}^{\infty} \beta^{s-t} \{\log \frac{C_s - \chi H_s}{1-\chi} - \kappa a_s^L \frac{L_s(h)^{1+\varphi}}{1+\varphi}$$
$$-\Lambda_s[\dots + P_s^C C_s(h) \dots - (1-\tau^W) W_s(h) L_s(h)]\}.$$

This generalization ($\varphi = 0$ in the g3 model) implies a change of equation (A.5) to

$$\frac{\kappa l_t^{\varphi}}{\lambda_t} markup^L = (1-\tau^W) w_t \tag{A.7}$$

and equation (A.6) changes to

$$\log\left(\frac{\pi_t^w}{\pi_{t-1}^w}\right) = \beta \log\left(\frac{\pi_{t+1}^w}{\pi_t^w}\right) - \frac{(1-\beta\xi^L)(1-\xi^L)}{\xi^L(1+\varepsilon^W \varphi)} \log\left(\frac{markup_t^L}{markup^L}\right) + \varepsilon_t^{labor}.$$

It is further assumed that the nominal wage is determined by the last hour worked that somebody is willing to offer without a markup, i.e. the higher the nominal wage per hour, the higher the willingness to work

$$\frac{\kappa LF_t^{\varphi}}{\lambda_t} = (1-\tau^W) w_t. \tag{A.8}$$

This assumption induces a labour force $LF_t$ and unemployment $u_t = \frac{LF_t}{l_t}$. Equation (A.7) can then be modified to

$$markup^L = \frac{(1-\tau^W) w_t}{\kappa l_t^{\varphi}} \lambda_t = \frac{(1-\tau^W) w_t}{\kappa (\frac{LF_t}{u_t})^{\varphi}} \lambda_t,$$

which, under condition (A.8), yields

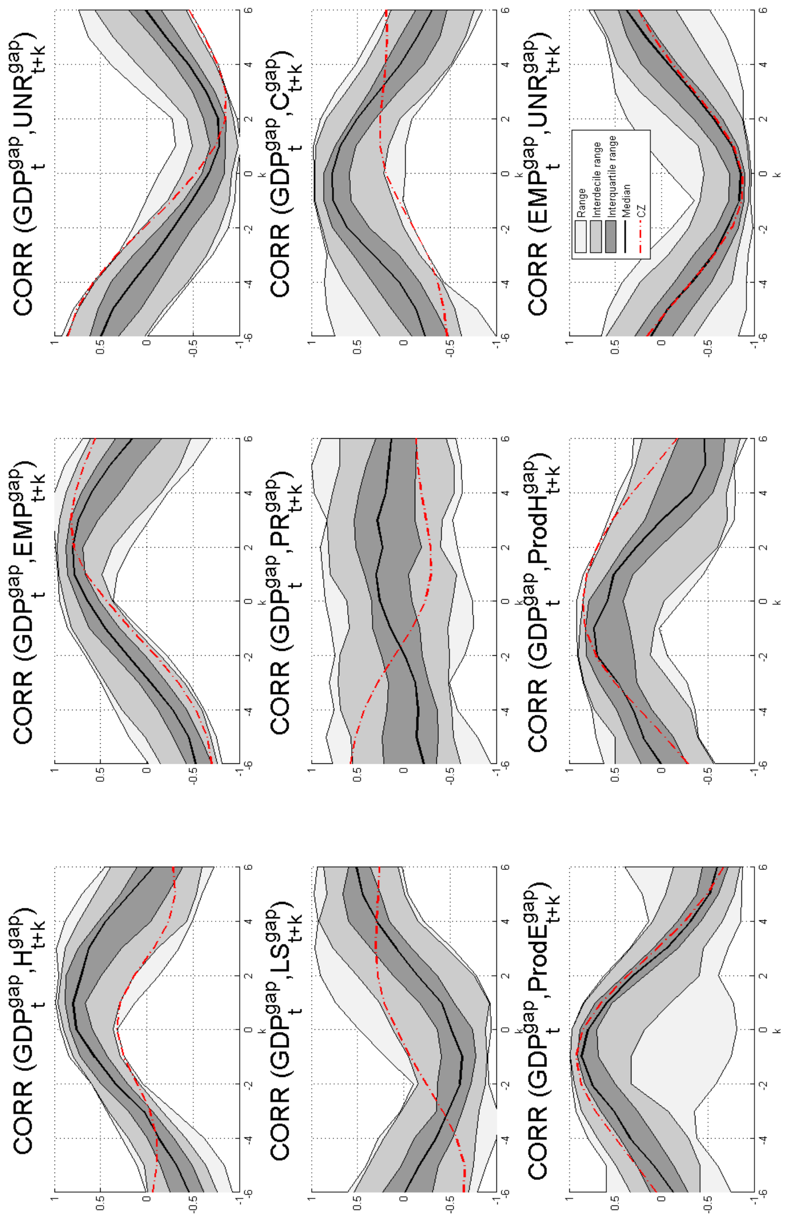
$$markup^L = u_t^{\varphi}.$$

Variables $LF_t$ and $l_t$ are stationarized here. Equation (A.7) is stationarized as in (A.4) and in equation $u_t = \frac{aL_t LF_t}{aL_t l_t} = \frac{LF_t}{l_t}$. If we assume that variable $ell_t$ in equation $w_t(1-\tau^S) ell_t = \gamma q_t^Y y_t$ equals $l_{t-1}$, i.e. that labour used for producing intermediate products is lagged labour from optimizing households, then we would stationarize according to $ell_t = \frac{aL_t}{aL_{t-1}} l_{t-1}$. Both options were tested and no substantial difference was found.

### A.5 Properties of Observed Variables for the Czech Case

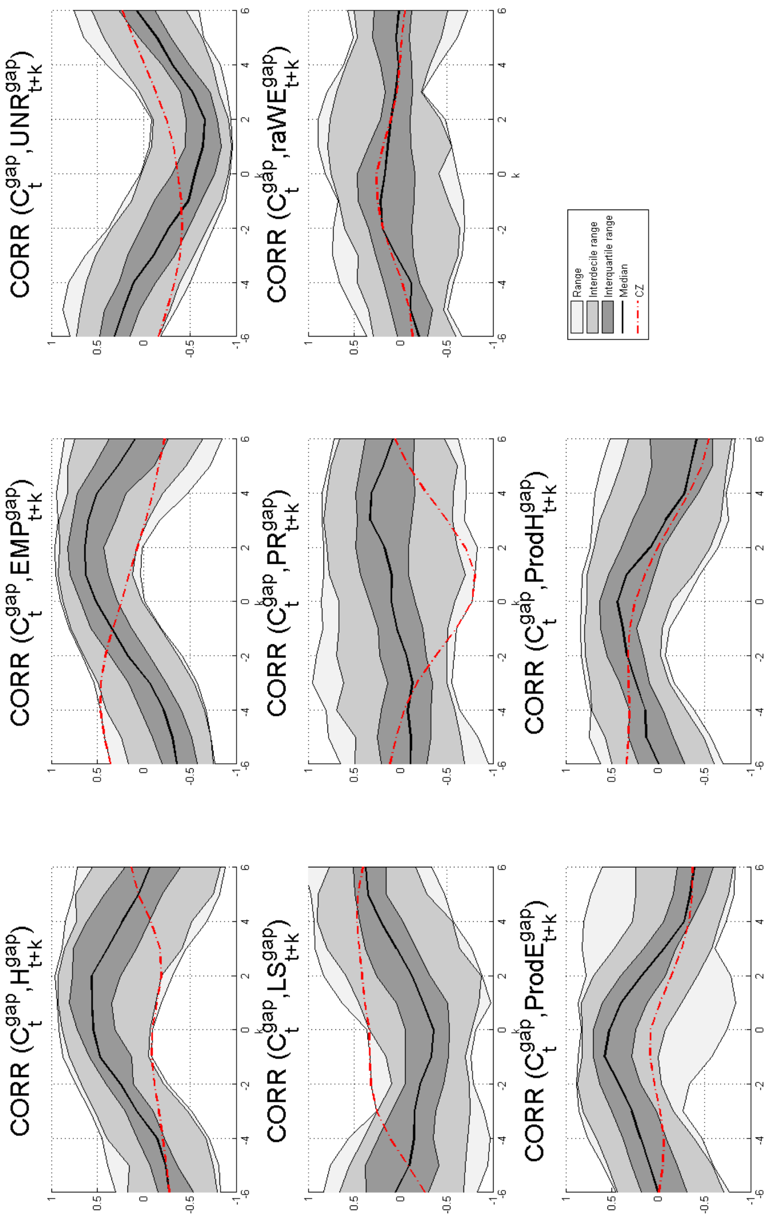
The correlation of the GDP gap with labour market gaps is high; the correlation of the consumption gap with labour market gaps is weak (see Brůha and Polanský, 2013).

***Figure A4: Correlation of the GDP Gap with Labour Market Gaps***



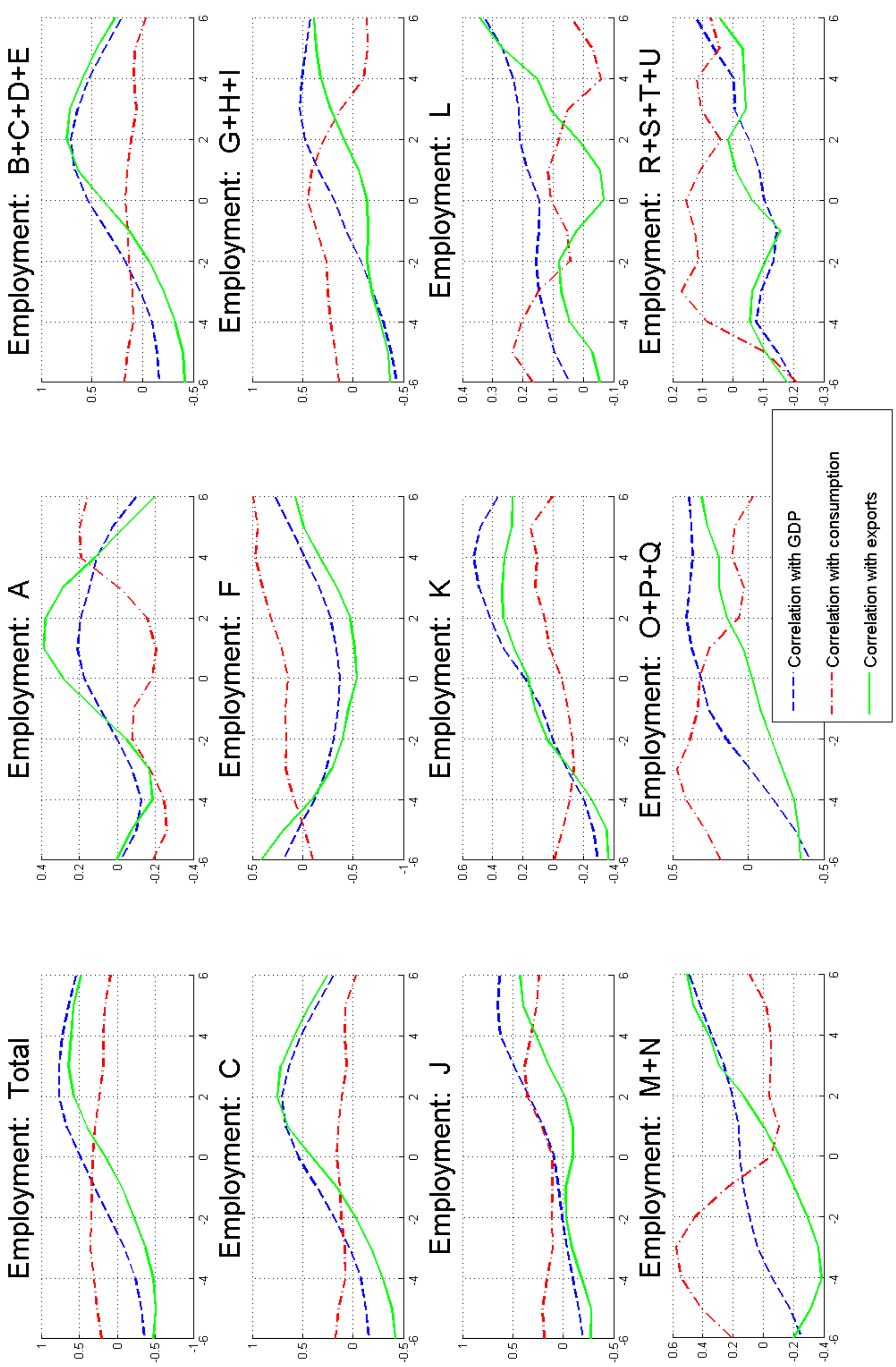
***Notes***: The graphs contain estimates of the correlation coefficients of the real GDP gap and the lags and leads of different labour market variables: hours worked (H), employment (EMP), unemployment rate (UNR), labour supply (LS), productivity (PR), consumption (C), productivity per employee (ProdE), productivity per hour (ProdH).

***Figure A5: Correlation of the Consumption Gap with Labour Market Gaps***




***Notes***: The graphs contain estimates of the correlation coefficients of the real consumption gap and the lags and leads of different labour market variables: hours worked (H), employment (EMP), unemployment rate (UNR), labour supply (LS), productivity (PR), consumption (C), productivity per employee (ProdE), productivity per hour (ProdH).

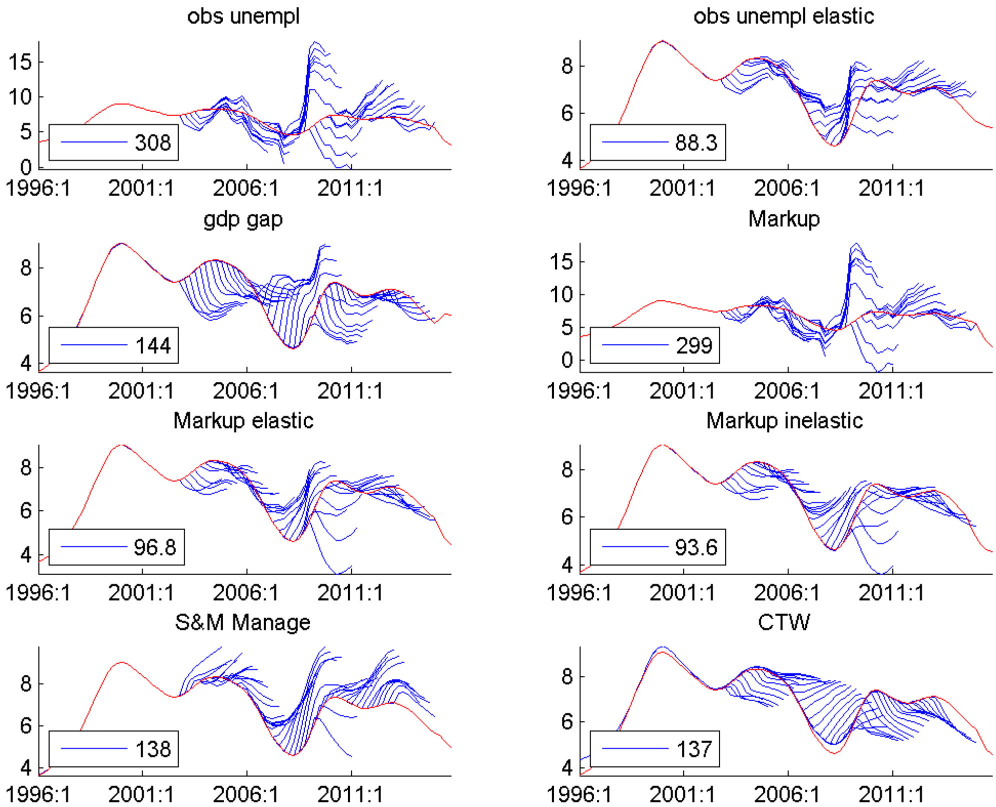
***Figure A6: Correlation of Employment in Various Sectors with GDP, Consumption and Exports***




***Notes***: The graphs contain estimates of the correlation between the real GDP gap (blue), the real consumption gap (red), the real exports gap (green) and the employment gap in various economic sectors. The classification of economic sectors follows NACE, rev. 2 (see http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN).

## A.6 In-sample Simulations

***Figure A7: In-sample Simulation of Unemployment – Chosen Concepts***




***Notes***: The graphs show in-sample simulations of the unemployment rate (blue) together with the RMSFE statistic of the conditional eight-steps-ahead forecast for alternative labour market concepts. Historical data are depicted in red.

The following tables report the RMSFE of the eight-steps-ahead prediction of the observed variables, such as the policy rate (IR), CPI inflation (CPI), the nominal exchange rate (ER), real GDP (GDP), nominal wage growth (W), real consumption (C), real investment (I), real exports (X), real imports (N) and their deflators (PC, PJ, PX and PN). The numbers in the tables correspond to the increase or decrease in the prediction error expressed in per cent of the prediction error of the baseline model. An improvement (deterioration) in predictive ability is therefore indicated by negative (positive) values in the table.

## *Table A1: In-sample Simulation Statistics for Observed Variables – Period 2002Q1 to 2015Q1*

| **model** | *calvo* | *calvo obs unempl* | *data change* | *obs unempl* | *obs unempl elastic* | *gdp gap* |
|---|---|---|---|---|---|---|
| **horizon** | 8 | 8 | 8 | 8 | 8 | 8 |
| **IR** | -6 | 1 | 1 | 3 | 18 | 0 |
| **CPI** | -0 | 1 | 0 | -0 | 0 | -2 |
| **ER** | -17 | -22 | 2 | -12 | -17 | -21 |
| **GDP** | -3 | -3 | -2 | -4 | -6 | 1 |
| **W** | -1 | -6 | 11 | -13 | 10 | -16 |
| **C** | -0 | 3 | -2 | -0 | 11 | 19 |
| **I** | 2 | 2 | 0 | 0 | 1 | 0 |
| **X** | -1 | -1 | -0 | -0 | -0 | 0 |
| **N** | -0 | -0 | -0 | 0 | -0 | 1 |
| **PC** | -0 | 1 | -0 | -1 | -1 | -2 |
| **PI** | -1 | -1 | -0 | -1 | -2 | -1 |
| **PX** | -4 | -4 | 1 | -1 | -2 | -1 |
| **PN** | -5 | -6 | 1 | -2 | -3 | -4 |
| **SUM** | -37.9 | -35.3 | 10.9 | -31.4 | 10.0 | -25.4 |
| **UR** | ∞ | -0 | ∞ | 0 | -71 | -53 |
| **SUM UR** | ∞ | -35.6 | ∞ | -31.4 | -61.3 | -78.8 |

| **model** | *Markup* | *Markup elastic* | | | *Markup inelastic* | *S&M Manage* | | | *CTW* |
|---|---|---|---|---|---|---|---|---|---|
| **horizon** | 8 | 6 | 8 | 10 | 8 | 6 | 8 | 10 | 8 |
| **IR** | 22 | 2 | 1 | 6 | 1 | 10 | 2 | 2 | -5 |
| **CPI** | 1 | 1 | 0 | 0 | -0 | 0 | 1 | 1 | -4 |
| **ER** | -6 | -22 | -22 | -24 | -23 | -20 | -16 | -12 | 4 |
| **GDP** | -2 | 2 | 2 | 1 | -1 | 4 | 4 | 4 | -8 |
| **W** | -34 | 1 | 1 | -5 | 7 | -8 | -12 | -20 | 27 |
| **C** | 5 | 8 | 6 | 4 | 7 | 9 | 12 | 12 | -9 |
| **I** | -0 | 5 | 4 | 3 | -1 | 6 | 7 | 6 | 3 |
| **X** | -1 | -0 | -1 | -1 | -1 | -0 | -1 | -1 | -2 |
| **N** | -0 | 0 | 0 | 0 | -0 | -1 | -1 | -1 | -2 |
| **PC** | 2 | 1 | 1 | 1 | -0 | 2 | 2 | 2 | -4 |
| **PI** | 1 | -2 | -2 | -2 | -3 | -1 | -1 | -1 | 14 |
| **PX** | -3 | -4 | -4 | -5 | -4 | -8 | -7 | -7 | 15 |
| **PN** | -1 | -5 | -5 | -5 | -6 | -5 | -6 | -6 | 7 |
| **SUM** | -16.4 | -12.4 | -20.1 | -26.4 | -24.1 | -11.6 | -18.2 | -21.1 | 35.2 |
| **UR** | -3 | -69 | -69 | -70 | -70 | -54 | -55 | -58 | -54 |
| **SUM UR** | -19.1 | -81.0 | -88.6 | -96.2 | -93.7 | -65.2 | -73.3 | -79.4 | -18.9 |

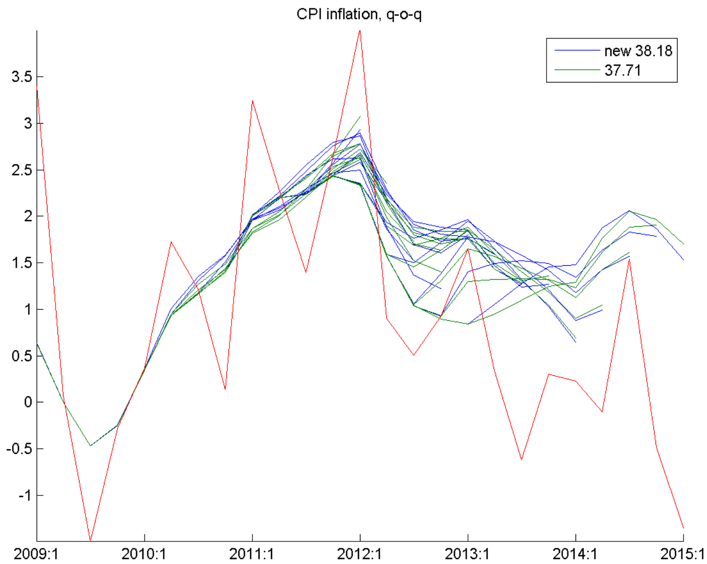
***Notes***: The table presents the changes in the prediction errors for the individual observed variables in comparison to the baseline model expressed in per cent of the original RMSFE (rounded to the nearest integer). The row denoted as *SUM* contains the metric of overall predictive ability change, which is calculated as the sum of the individual changes shown above. The row denoted as *UR* contains the relative change in the predictive ability of the unemployment rate with respect to the *obs unempl* model specification. The row *SUM UR* contains the sum of the two rows *SUM* and *UR*. Negative (positive) values correspond to an improvement (deterioration) in predictive ability. The default prediction horizon is eight quarters. For the *Markup-elastic* and *S&M-Manage* concepts, more detailed results with additional prediction horizons of six and ten quarters are given as well.

***Table A2: In-sample Simulation Statistics for Observed Variables – Period 2010Q1 to 2015Q1***

| **model** | *calvo* | *calvo obs unempl* | *data change* | *obs unempl* | *obs unempl elastic* | *gdp gap* | *Markup* | *Markup elastic* | *Markup inelastic* | *S&M Manage* | *CTW* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **horizon** | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| **IR** | -4 | 40 | 6 | -1 | 15 | -9 | 72 | 8 | 1 | 55 | 21 |
| **CPI** | -1 | 5 | 0 | -2 | -1 | -6 | 8 | 1 | -5 | 4 | -4 |
| **ER** | -41 | -52 | 9 | -24 | -23 | -45 | -49 | -39 | -34 | -36 | -3 |
| **GDP** | 0 | 5 | 1 | 1 | 4 | 19 | 4 | 6 | -12 | 8 | -23 |
| **W** | -39 | -46 | 1 | -26 | -26 | -30 | -51 | -14 | -7 | -20 | -11 |
| **C** | 2 | 12 | -2 | 10 | 20 | 68 | 8 | 6 | 8 | 3 | 7 |
| **I** | -1 | -2 | 1 | -1 | -1 | -7 | -3 | 1 | -19 | -1 | -14 |
| **X** | 0 | -0 | -0 | 0 | 0 | 0 | 0 | 1 | -2 | -1 | -0 |
| **N** | 1 | 1 | -0 | 1 | 1 | 3 | 1 | 1 | -1 | -1 | -1 |
| **PC** | -1 | 1 | -0 | -2 | -2 | -4 | 2 | 1 | -2 | 1 | -4 |
| **PI** | 0 | 1 | -0 | -0 | -0 | 1 | -0 | 0 | -4 | -0 | 5 |
| **PX** | -3 | -4 | 1 | -1 | -1 | 0 | -4 | -3 | -2 | -6 | 4 |
| **PN** | -7 | -6 | 2 | -4 | -4 | -6 | -5 | -8 | -9 | -5 | -4 |
| **SUM** | -93.7 | -45.5 | 18.2 | -49.2 | -17.5 | -15.1 | -17.1 | -37.2 | -89.9 | 1.1 | -25.7 |
| **UR** | ∞ | -16 | ∞ | 0 | -73 | -76 | -15 | -79 | -82 | -38 | -54 |
| **SUM UR** | ∞ | -61.6 | ∞ | -49.2 | -90.8 | -90.6 | -31.8 | -116.2 | -172.1 | -36.5 | -79.3 |

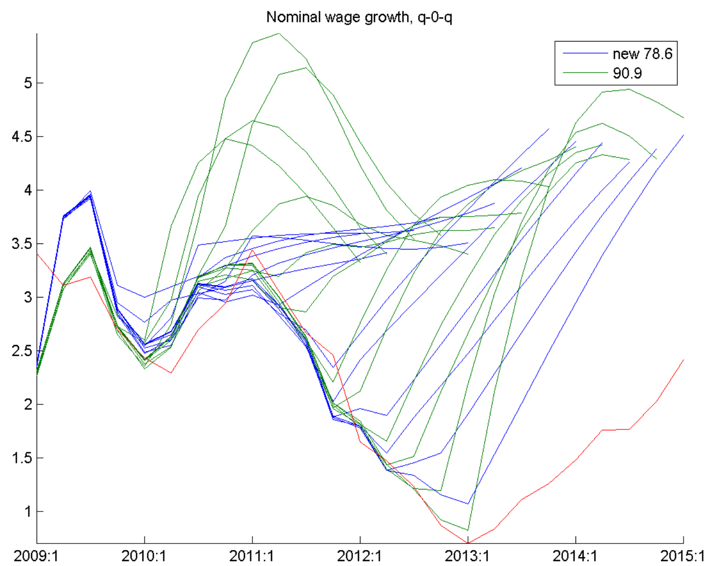
***Notes***: The table presents the changes in the prediction errors for the individual observed variables in comparison to the baseline model expressed in per cent of the original RMSFE (rounded to the nearest integer). The row denoted as *SUM* contains the metric of overall predictive ability change, which is calculated as the sum of the individual changes shown above. The row denoted as *UR* contains the relative change in the predictive ability of the unemployment rate with respect to the *obs unempl* model specification. The row *SUM UR* contains the sum of the two rows *SUM* and *UR*. Negative (positive) values correspond to an improvement (deterioration) in predictive ability. The presented results correspond to a prediction horizon of eight quarters.

***Figure A8: In-sample Simulations of Inflation in the Crisis Period – Markup-elastic***



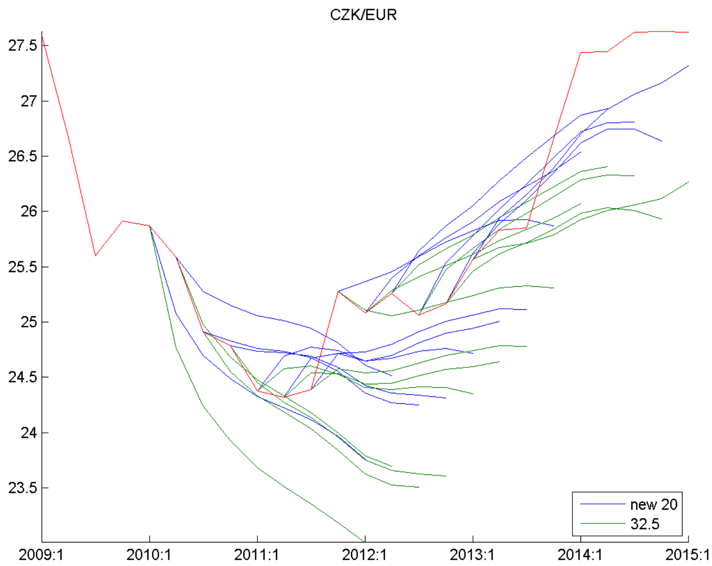

***Notes***: The graph contains in-sample simulations of the annual inflation rate as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A9: In-sample Simulations of Nominal Wage Growth in the Crisis Period – Markup-elastic***




***Notes***: The graph contains in-sample simulations of annual nominal wage growth as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A10: In-sample Simulations of the Nominal Exchange Rate in the Crisis Period – Markup-elastic***

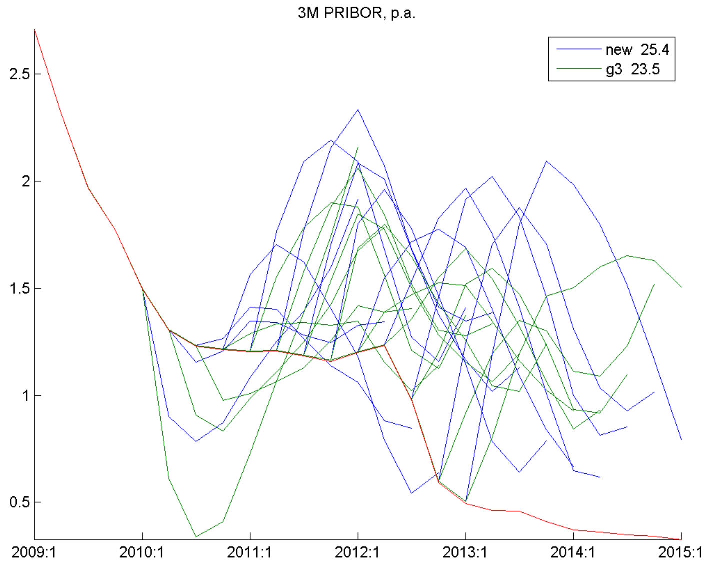



***Notes***: The graph contains in-sample simulations of the nominal exchange rate as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A11: In-sample Simulations of the Unemployment Rate in the Crisis Period – Markup-elastic***

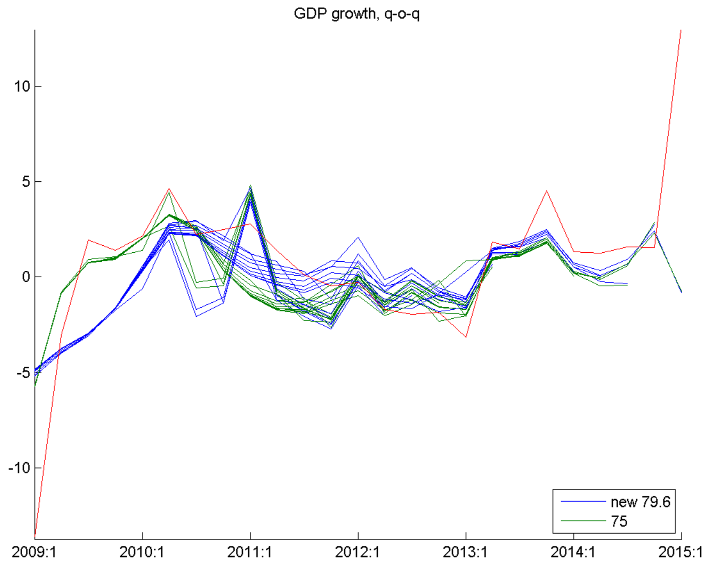

***Notes***: The graph contains in-sample simulations of the unemployment rate as calculated by the *Markup-elastic* model (blue) together with the RMSFE statistic of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A12: In-sample Simulations of the Nominal Interest Rate in the Crisis Period – Markup-elastic***



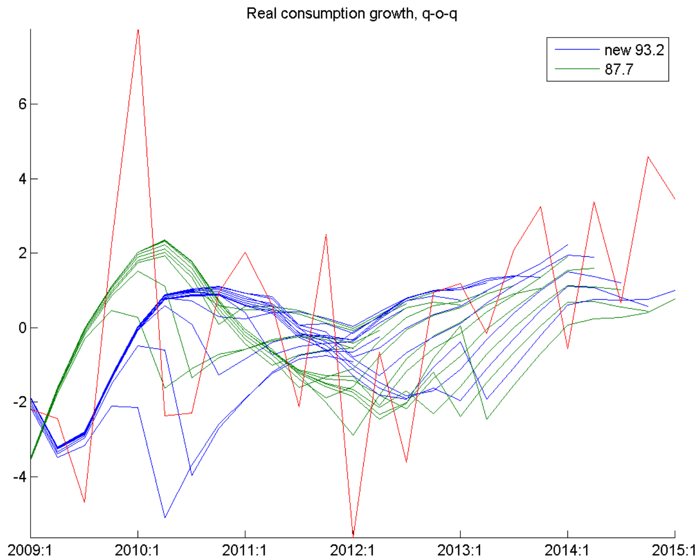

***Notes***: The graph contains in-sample simulations of the nominal interest rate as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A13: In-sample Simulations of the Real GDP Growth in the Crisis Period – Markup-elastic***



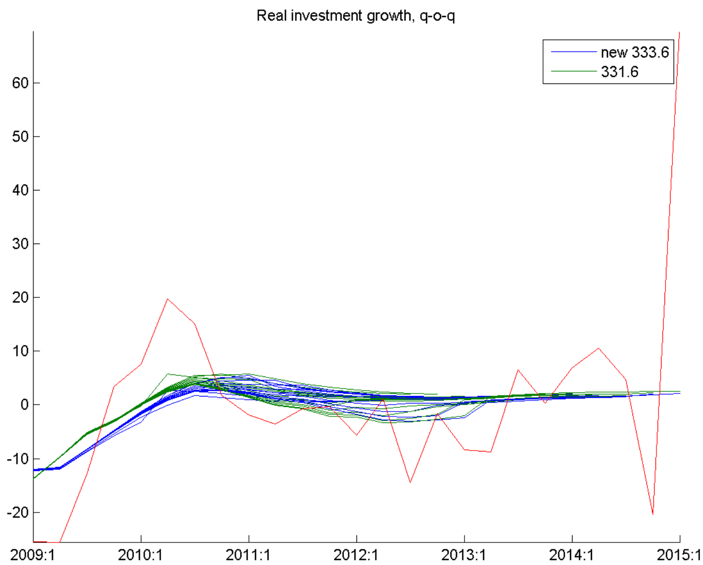

***Notes***: The graph contains in-sample simulations of the real GDP growth in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A14: In-sample Simulations of the Real Consumption Growth in the Crisis Period – Markup-elastic***



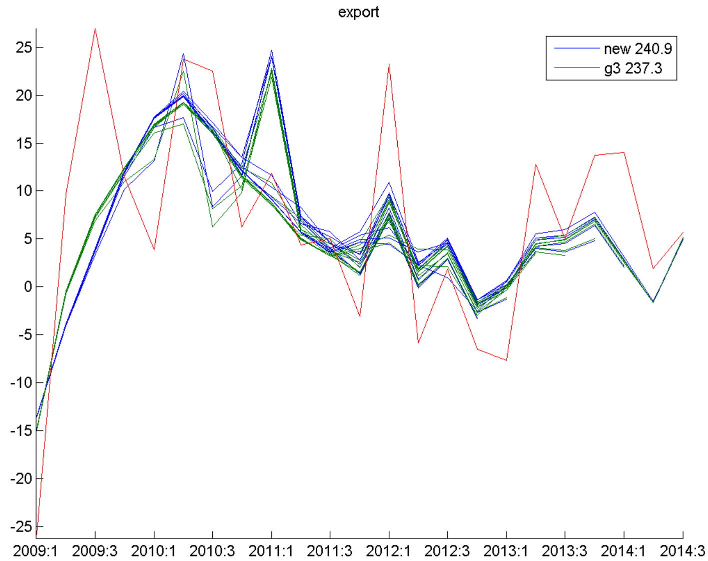

***Notes***: The graph contains in-sample simulations of the real consumption growth in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A15: In-sample Simulations of the Real Investment Growth in the Crisis Period – Markup-elastic***



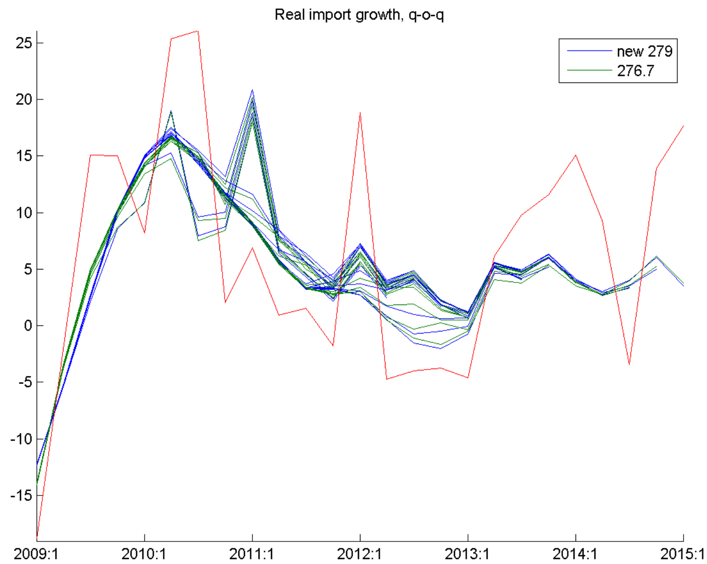

***Notes***: The graph contains in-sample simulations of the real investment gap in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A16: In-sample Simulations of the Real Export Growth in the Crisis Period – Markup-elastic***



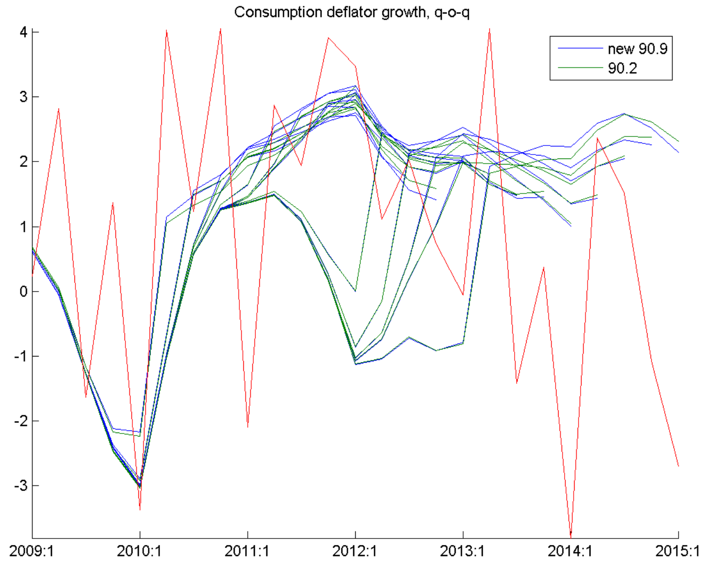

***Notes***: The graph contains in-sample simulations of the real export growth in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A17: In-sample Simulations of the Real Import Growth in the Crisis Period – Markup-elastic***



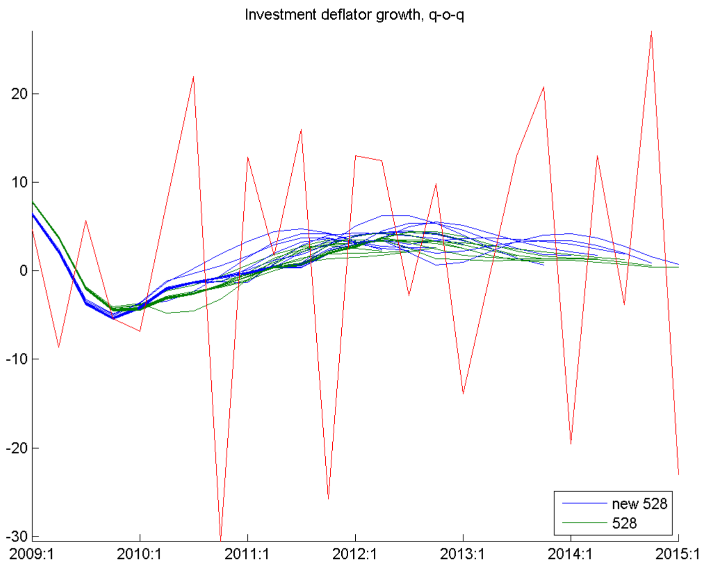

***Notes***: The graph contains in-sample simulations of the real import growth in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A18: In-sample Simulations of the Consumption Deflator in the Crisis Period – Markup-elastic***



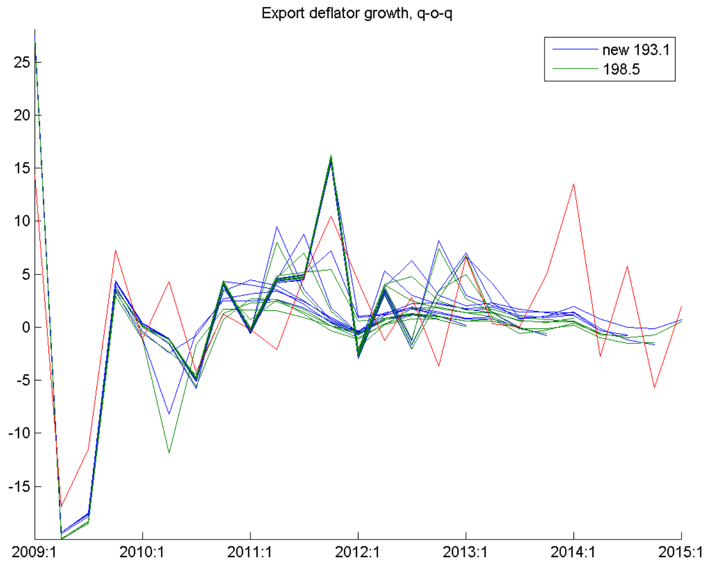

***Notes***: The graph contains in-sample simulations of the consumption deflator in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A19: In-sample Simulations of the Investment Deflator in the Crisis Period – Markup-elastic***



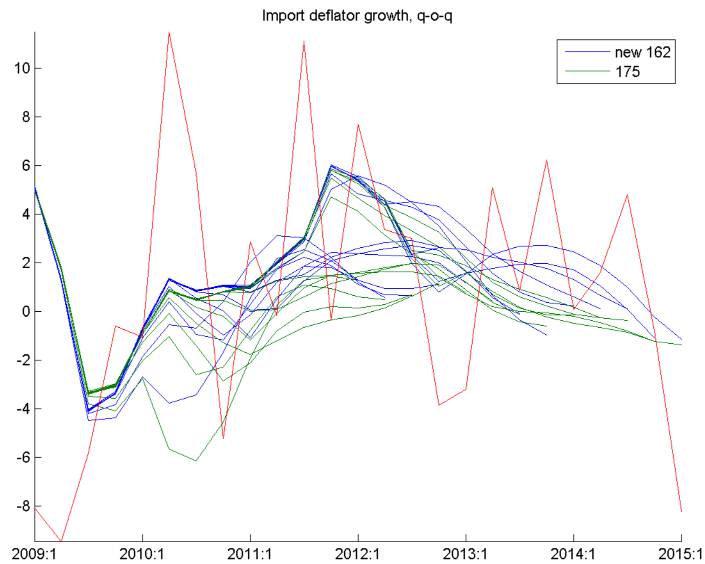

***Notes***: The graph contains in-sample simulations of the investment deflator in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A20: In-sample Simulations of the Export Deflator in the Crisis Period – Markup-elastic***




***Notes***: The graph contains in-sample simulations of the export deflator in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

***Figure A21: In-sample Simulations of the Import Deflator in the Crisis Period – Markup-elastic***



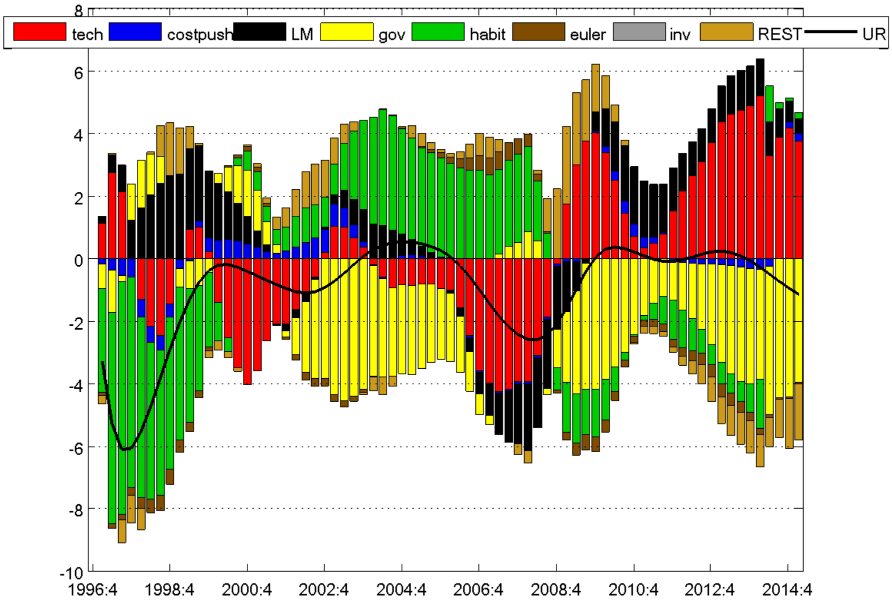

***Notes***: The graph contains in-sample simulations of the import deflator in per cent as calculated by the baseline model (green) and the *Markup-elastic* model (blue) together with the RMSFE statistics of the eight-steps-ahead prediction. Historical data are depicted in red.

## A.7 Shock Decomposition of Unemployment

The shock decompositions show a similar structural story for the *obs unempl* and *gdp gap* concepts and for the *Markup-inelastic* and *S&M-Manage* concepts.

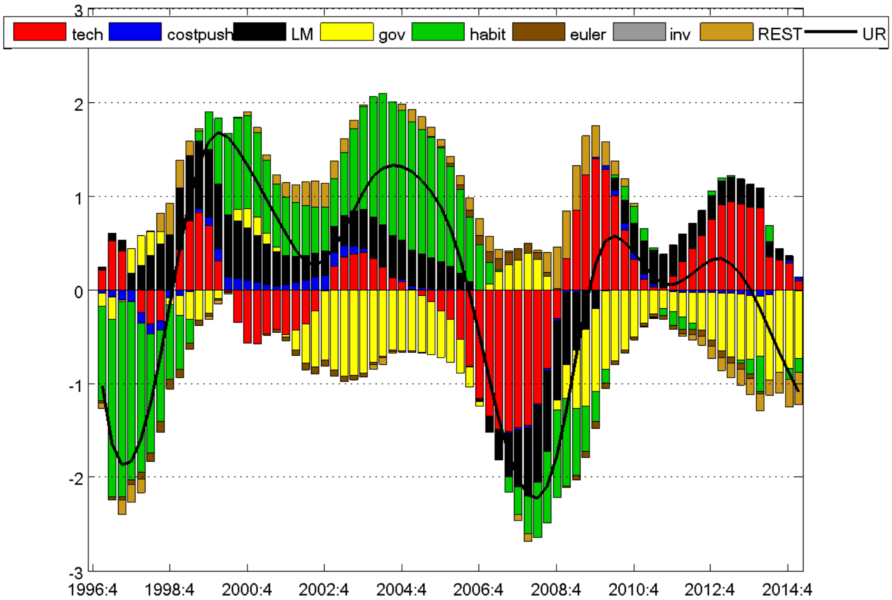
The *tech* label in the figures denotes technology shocks as labour-augmenting technology shocks and TFP shocks. The *costpush* label denotes cost-push shocks in the consumption, investment, government, export, import and intermediate sectors. The *Foreign* label denotes shocks to foreign variables, i.e. foreign demand, foreign interest rates and foreign prices. The *gov* label denotes government shocks. The *habit, euler, inv, UIP, MP* and *regul* labels denote habit in consumption, wedge in the Euler equation, investment specific, uncovered interest rate parity, monetary policy and regulated price shocks respectively. The *LM* label denotes labour market shocks. These are specific to the given labour market concept. It consists only of the wage cost-push shock in the *gdp gap*, *obs unempl*, *obs unempl-elastic* and *Markup* concepts. For the *S&M-Manage* and *CTW* concepts, there are additional shocks such as a matching function shock, a labour force shock and a bargaining power shock. The *REST* label comprises the effects of those shocks which do not appear in the legend (including the initial conditions).

***Figure A22: Shock Decomposition of the Unemployment Rate Gap – obs unempl***



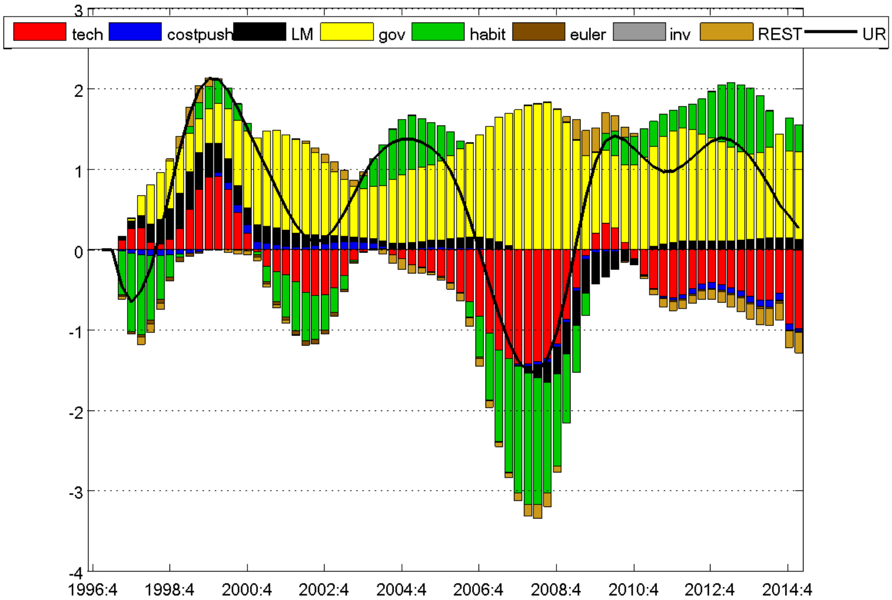

***Notes***: The graph denotes the historical shock decomposition of the unemployment rate gap in percentage points as calculated by the *obs unempl* model.

***Figure A23: Shock Decomposition of the Unemployment Rate Gap – obs unempl-elastic***



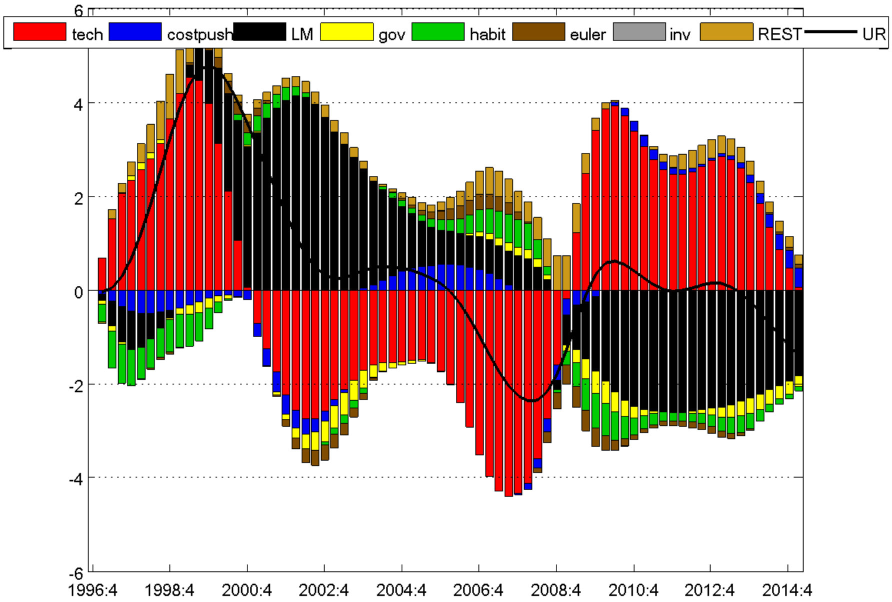

***Notes***: The graph denotes the historical shock decomposition of the unemployment rate gap in percentage points as calculated by the *obs unempl-elastic* model.

***Figure A24: Shock Decomposition of the Unemployment Rate Gap – gdp gap***



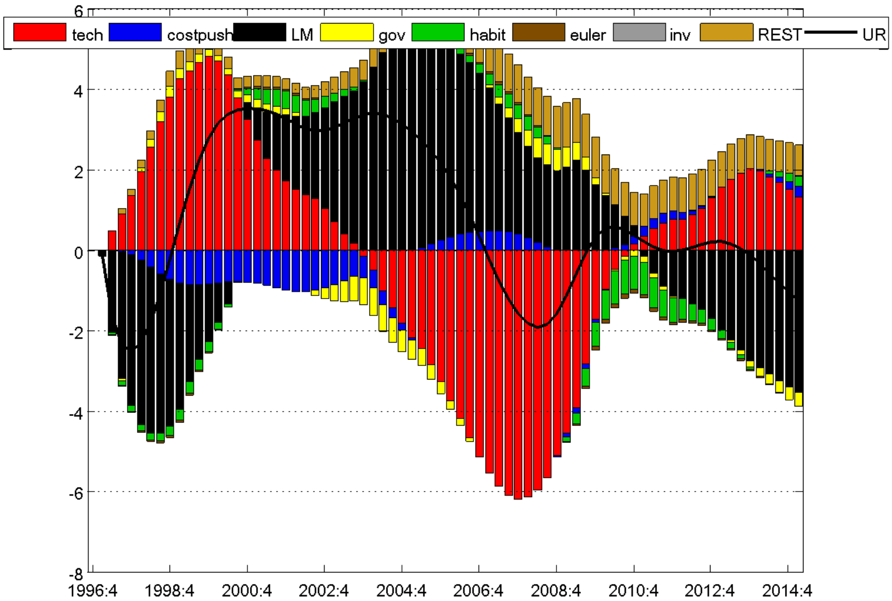

***Notes***: The graph denotes the historical shock decomposition of the unemployment rate gap in percentage points as calculated by the *gdp gap* model.

***Figure A25: Shock Decomposition of the Unemployment Rate Gap – Markup-elastic***



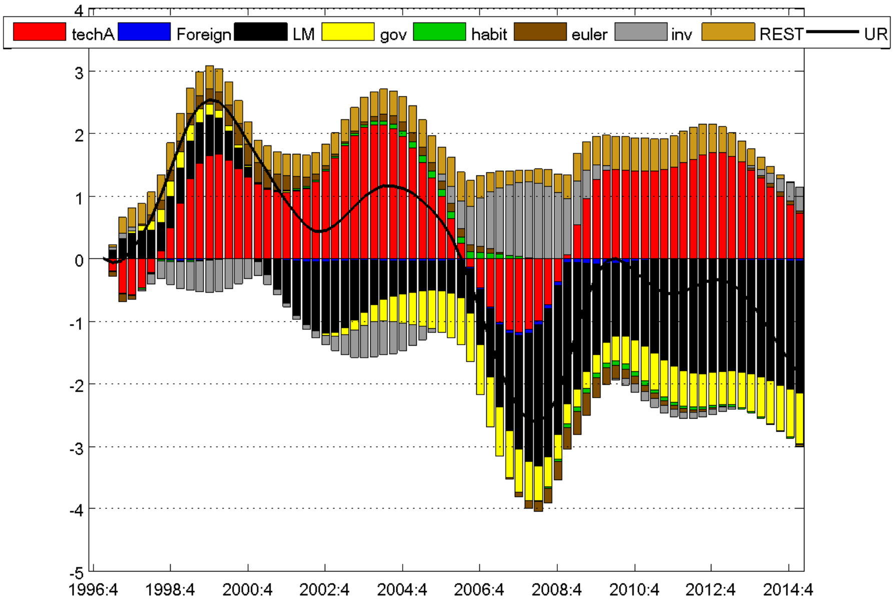

***Notes***: The graph denotes the historical shock decomposition of the unemployment rate gap in percentage points as calculated by the *Markup-elastic* model.

***Figure A26: Shock Decomposition of the Unemployment Rate Gap – S&M-Manage***




***Notes***: The graph denotes the historical shock decomposition of the unemployment rate gap in percentage points as calculated by the *S&M-Manage* model.

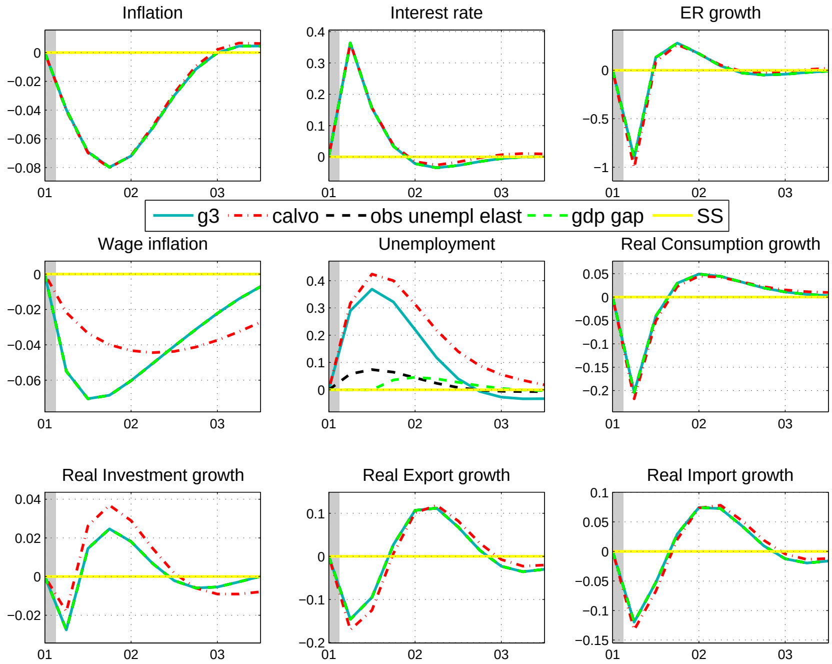
***Figure A27: Shock Decomposition of the Unemployment Rate Gap – CTW***




***Notes***: The graph denotes the historical shock decomposition of the unemployment rate gap in percentage points as calculated by the *CTW* model.

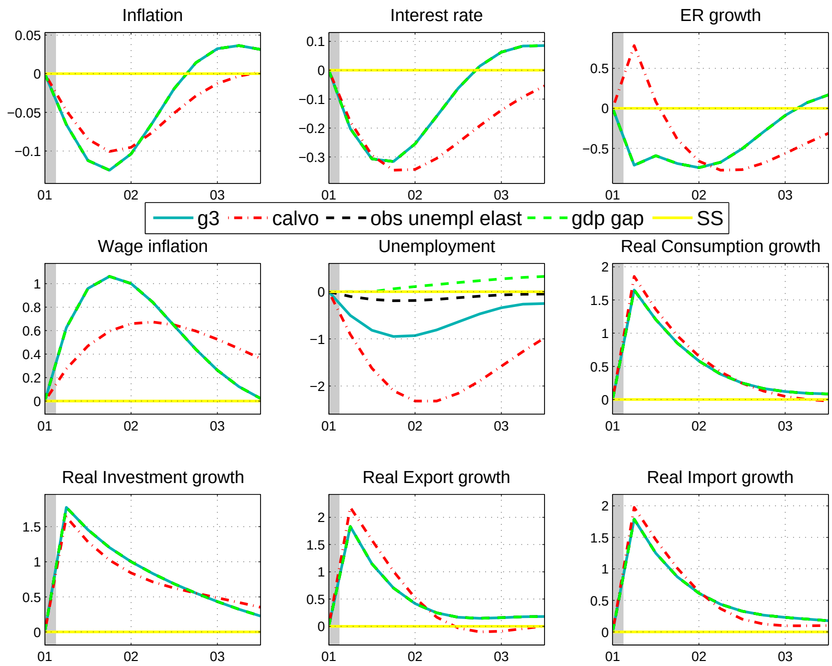
## A.8 Impulse Responses

### *Figure A28: Monetary Policy Shock*



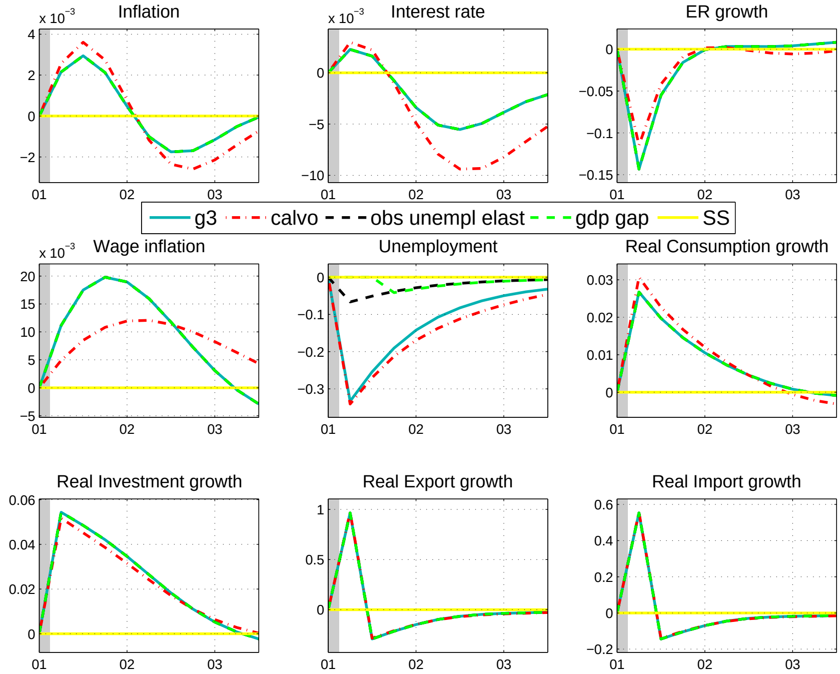

***Notes***: Deviations from the steady state are depicted in percentage points.

### *Figure A29: Labour-augmenting Technology Shock*



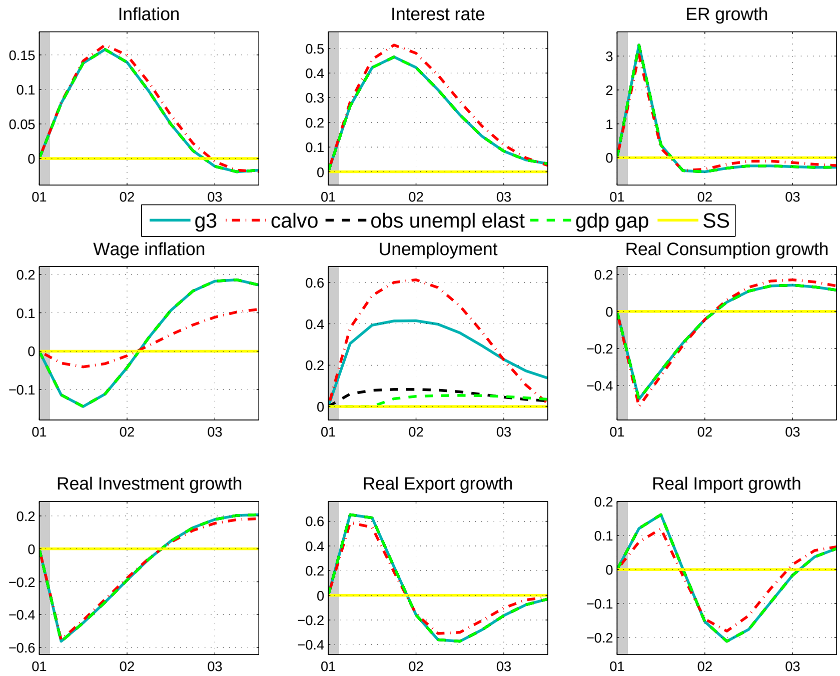

***Notes***: Deviations from the steady state are depicted in percentage points.

***Figure A30: Foreign Demand Shock***



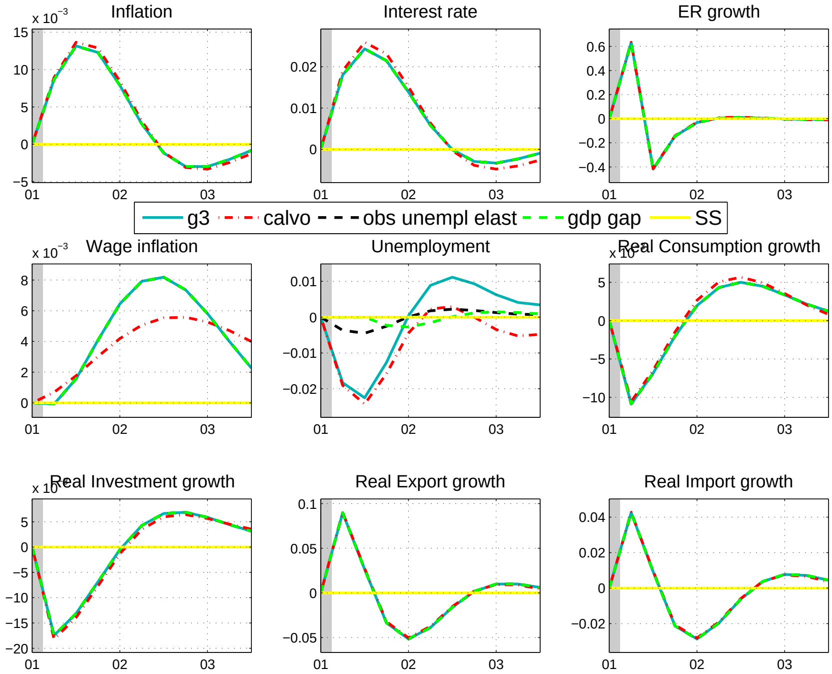

***Notes***: Deviations from the steady state are depicted in percentage points.

***Figure A31: Foreign Interest Rate Shock***



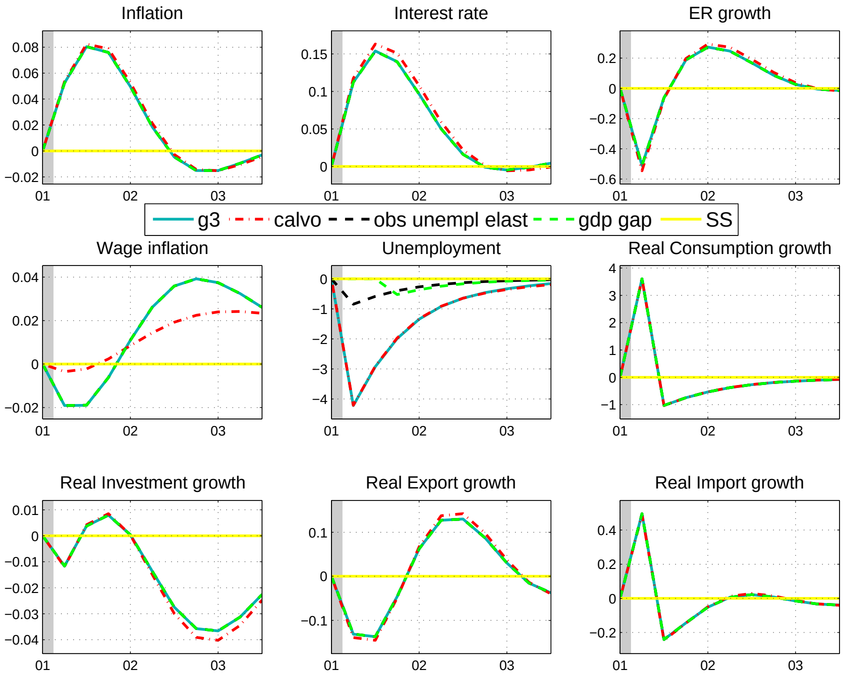

***Notes***: Deviations from the steady state are depicted in percentage points.

## *Figure A32: Debt-elastic Premium Shock*



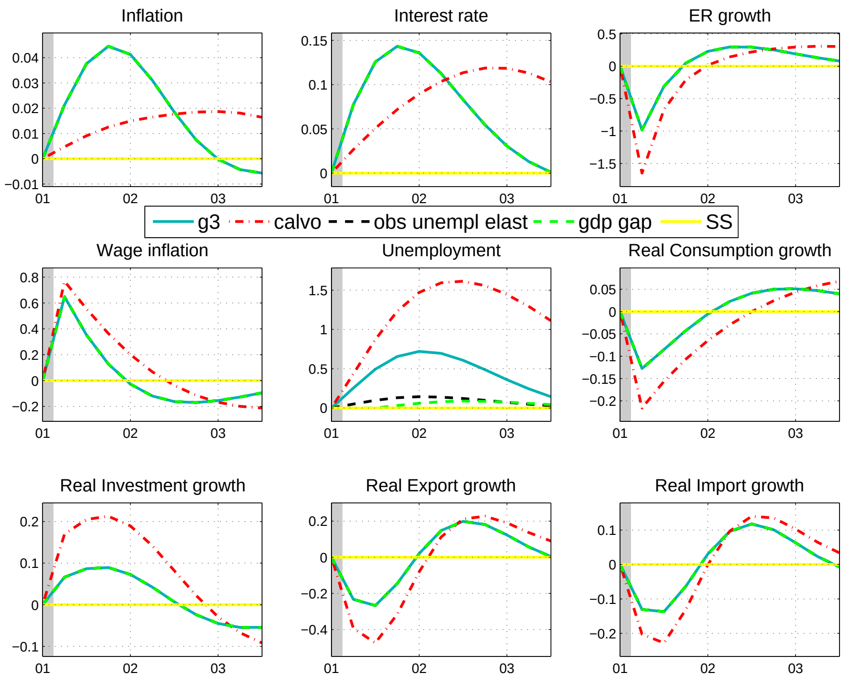

***Notes***: Deviations from the steady state are depicted in percentage points.

## *Figure A33: Habit Shock*



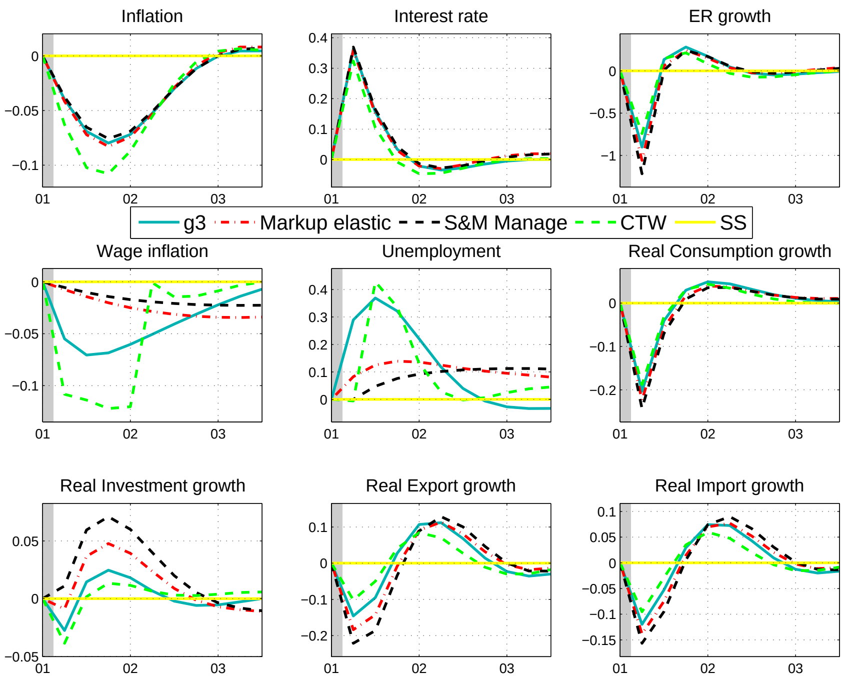

***Notes***: Deviations from the steady state are depicted in percentage points.

## *Figure A34: Wage Cost-push Shock*



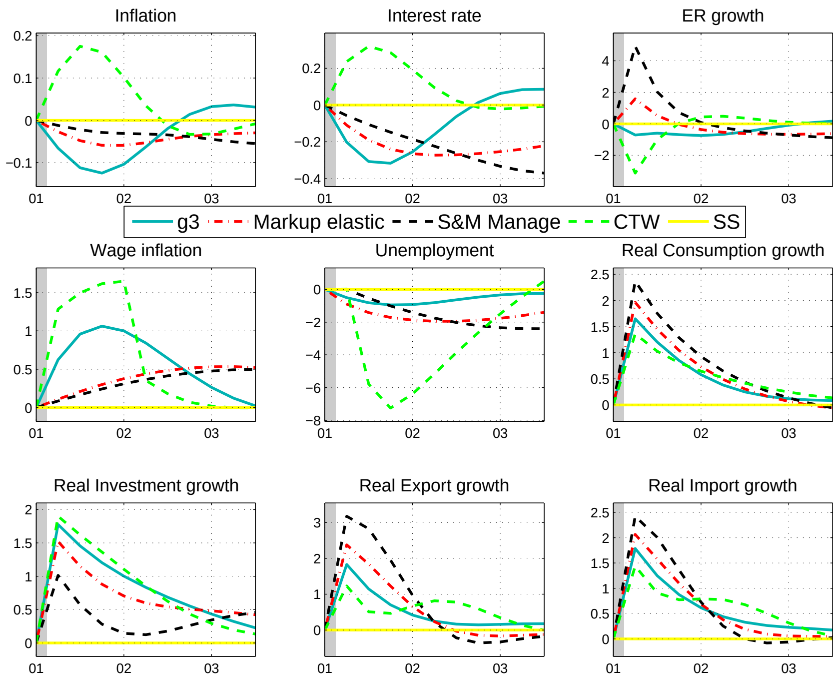

***Notes***: Deviations from the steady state are depicted in percentage points.

## *Figure A35: Monetary Policy Shock*



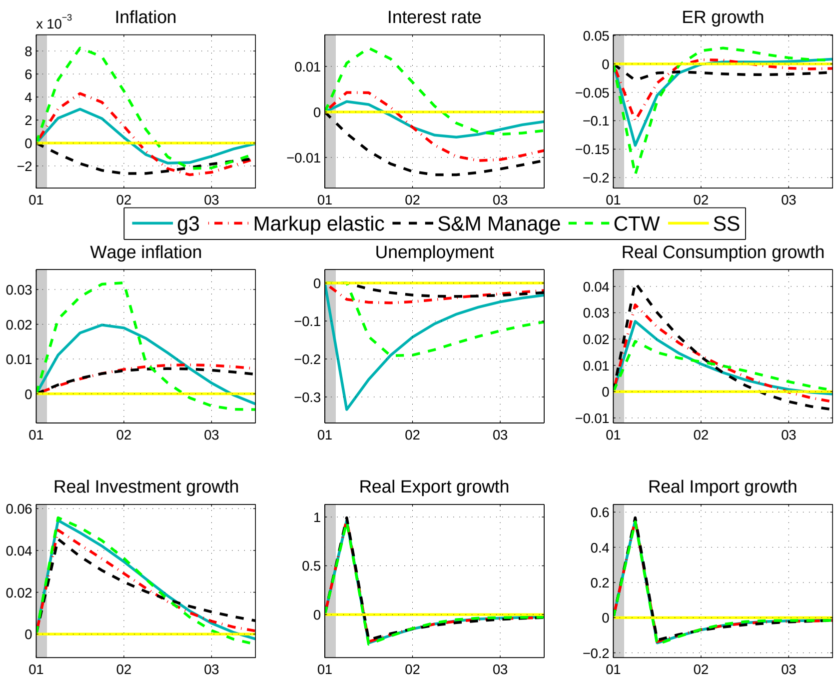

***Notes***: Deviations from the steady state are depicted in percentage points.

## *Figure A36: Labour-augmenting Technology Shock*



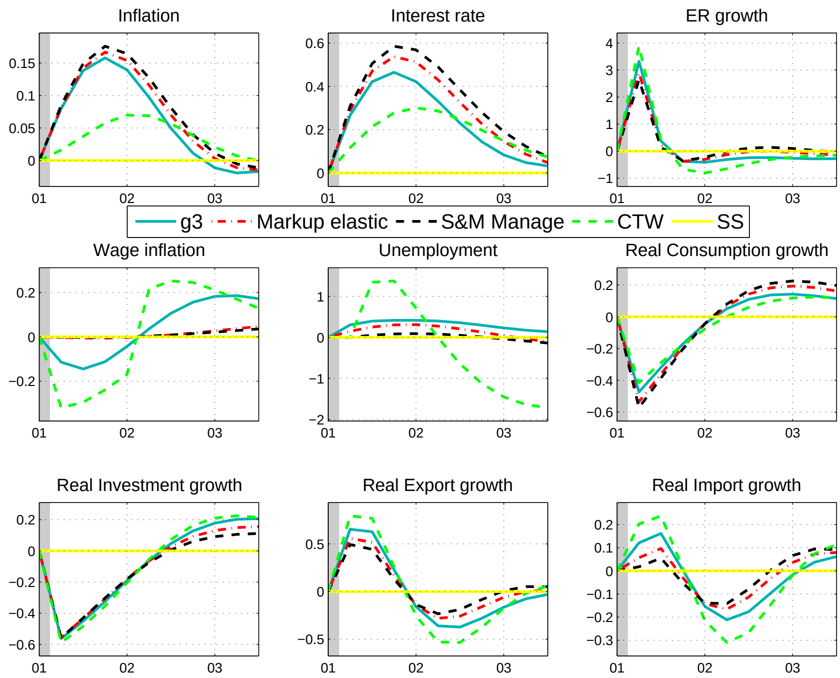

***Notes***: Deviations from the steady state are depicted in percentage points.

## *Figure A37: Foreign Demand Shock*



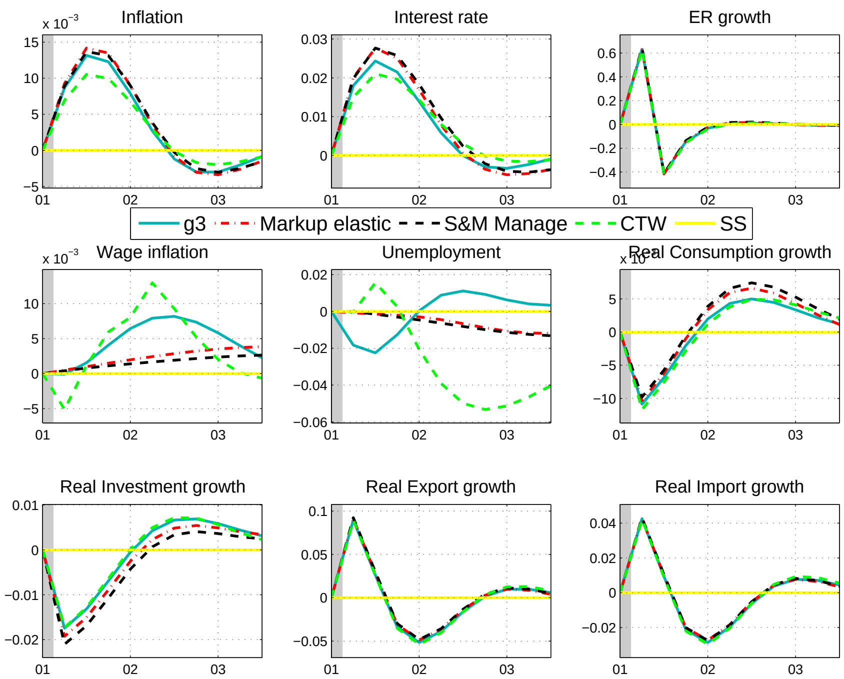

***Notes***: Deviations from the steady state are depicted in percentage points.

### *Figure A38: Foreign Interest Rate Shock*



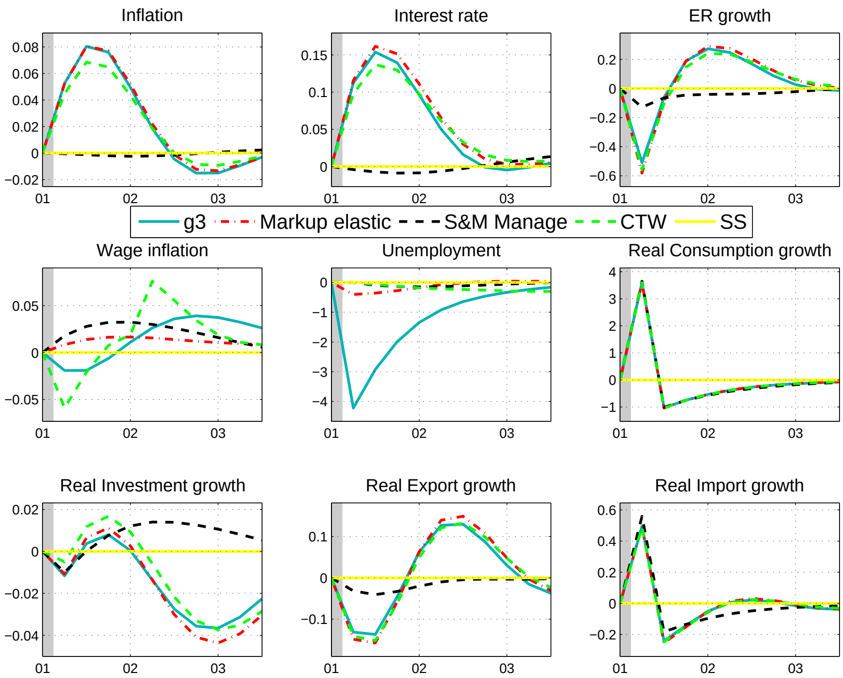

***Notes***: Deviations from the steady state are depicted in percentage points.

### *Figure A39: Debt-elastic Premium Shock*



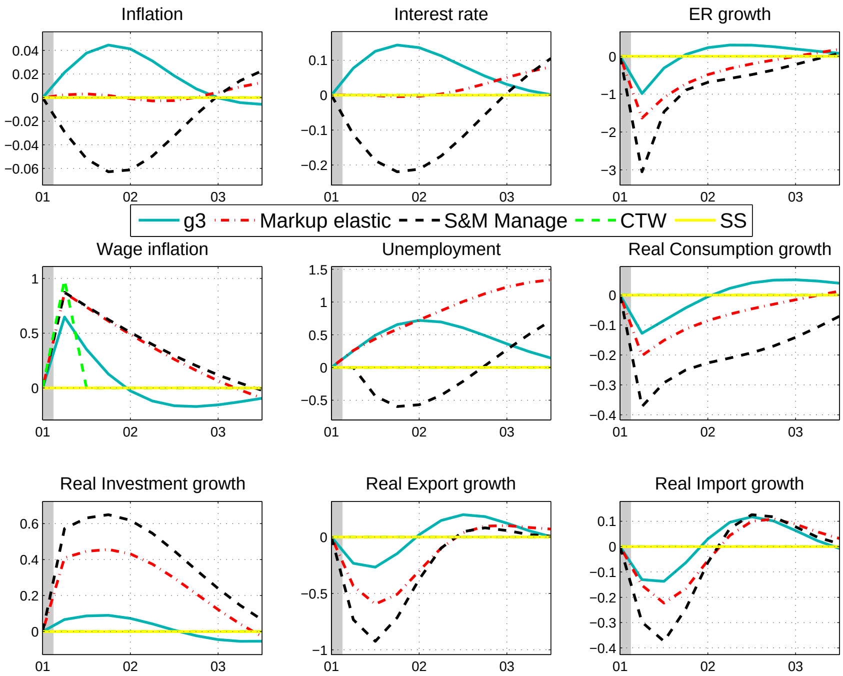

***Notes***: Deviations from the steady state are depicted in percentage points.

## *Figure A40: Habit Shock*




***Notes***: Deviations from the steady state are depicted in percentage points.

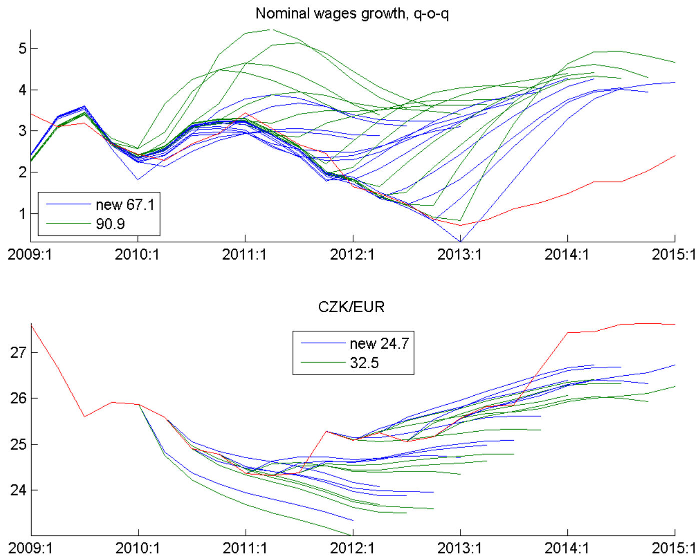
## *Figure A41: Wage Cost-push Shock*




***Notes***: Deviations from the steady state are depicted in percentage points.

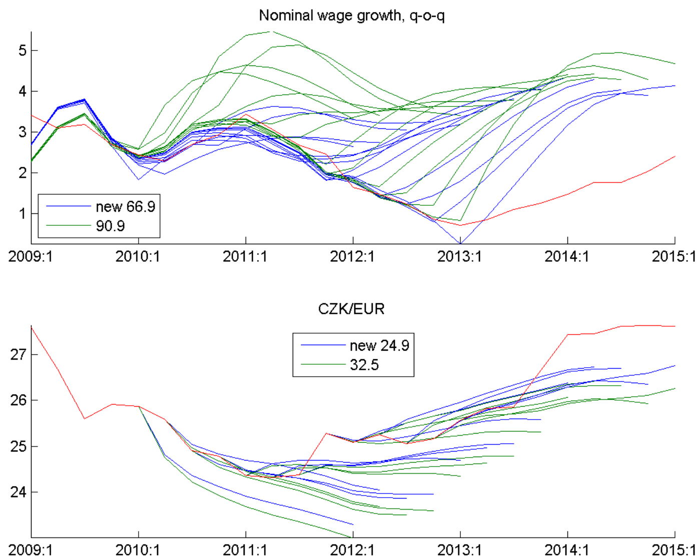
## A.9 In-sample Simulations in the Crisis Period

***Figure A42: In-sample Simulations in the Crisis Period – obs unempl***



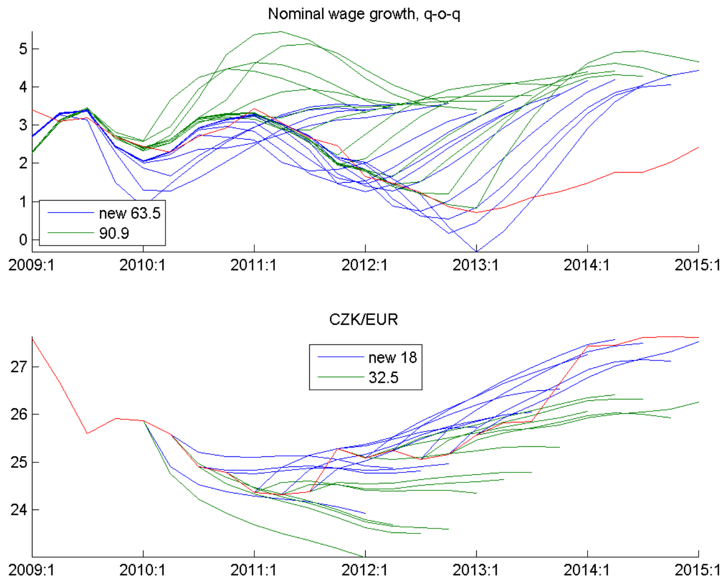

***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *obs unempl* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

***Figure A43: In-sample Simulations in the Crisis Period – obs unempl-elastic***



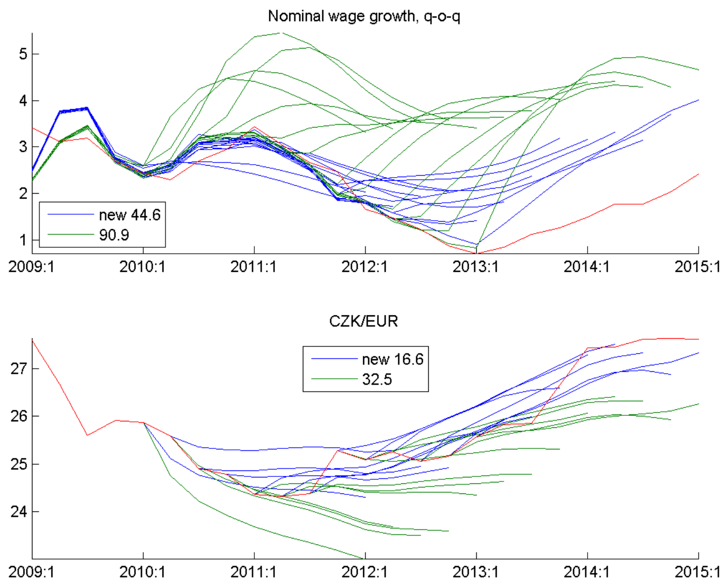

***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *obs unempl-elastic* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

***Figure A44: In-sample Simulations in the Crisis Period – gdp gap***



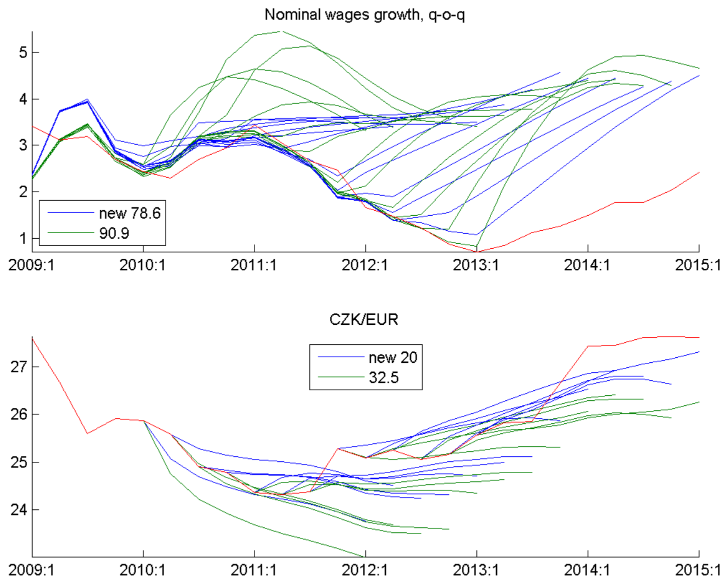

***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *gdp gap* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

***Figure A45: In-sample Simulations in the Crisis Period – Markup***



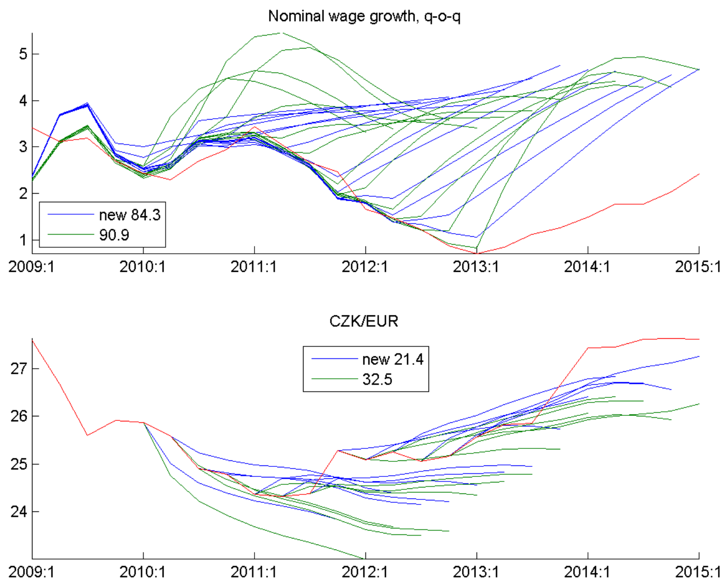

***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *Markup* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

***Figure A46: In-sample Simulations in the Crisis Period – Markup-elastic***



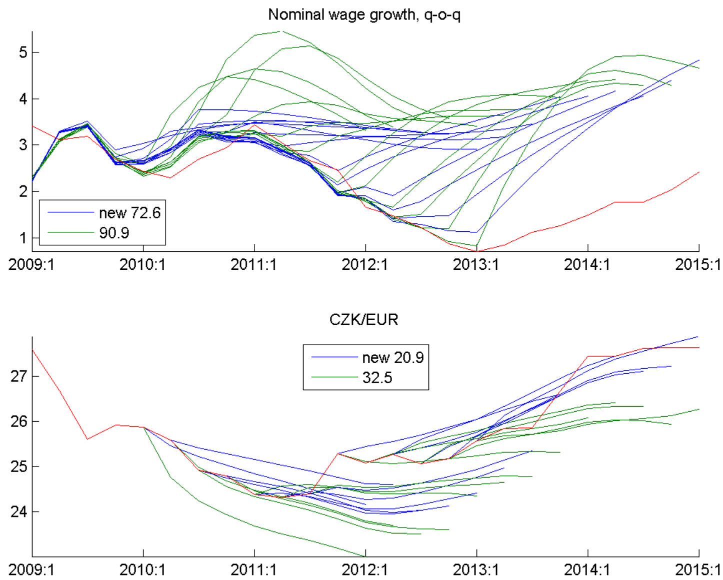

***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *Markup-elastic* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

***Figure A47: In-sample Simulations in the Crisis Period – Markup-inelastic***



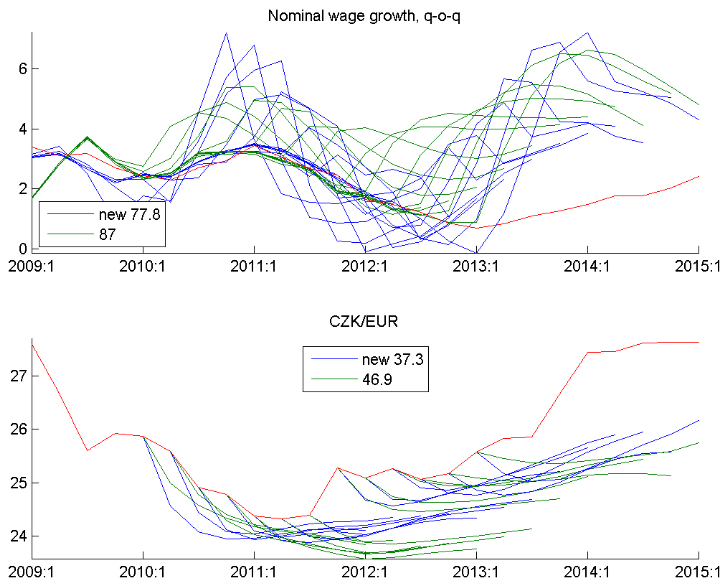

***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *Markup-inelastic* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

### *Figure A48: In-sample Simulations in the Crisis Period – S&M-Manage*




***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *S&M-Manage* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

### *Figure A49: In-sample Simulations in the Crisis Period – CTW*

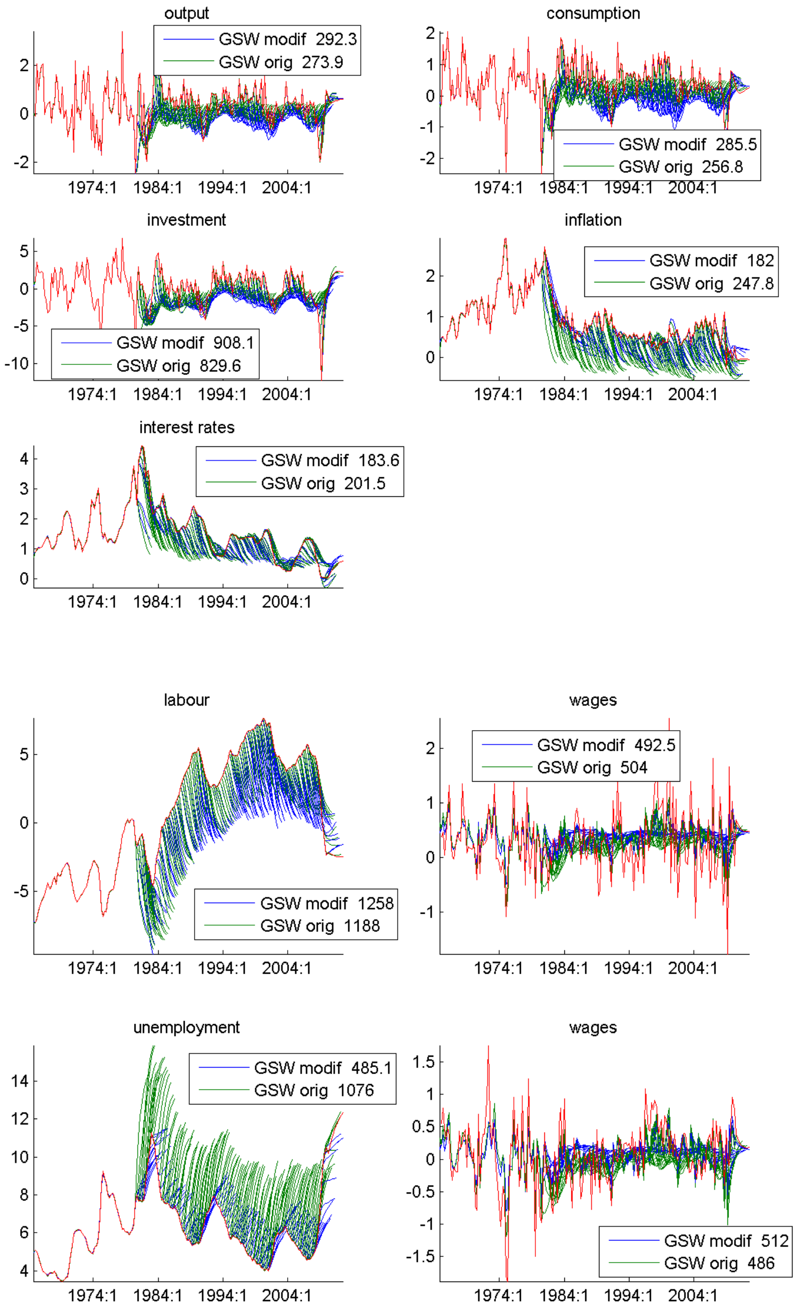



***Notes***: In-sample simulations of annual nominal wage growth (top) and the nominal exchange rate (bottom) as calculated by the baseline model (green) and the *CTW* model (blue) with the RMSFE statistic of the eight-steps-ahead prediction. Historical data in red.

## A.10 Original GSW Model In-sample Simulations

A reduction in employment elasticity yields a significant improvement in the predictive ability for unemployment.

***Figure A50: In-sample Simulations – Original GSW Model vs. GSW with Elasticity Reduction***




***Notes***: In-sample simulations of the main economic variables as calculated by the original GSW model (green) and its alternative with reduced elasticity of employment (blue) are compared in the graph. The RMSFE statistics of the eight-steps-ahead prediction are presented in boxes. Historical data are depicted in red.

| CNB WORKING PAPER SERIES | | |
|---|---|---|
| 6/2015 | Jaromír Tonner<br>Stanislav Tvrz<br>Osvald Vašíček | *Labour market modelling within a DSGE approach* |
| 5/2015 | Miroslav Plašil<br>Tomáš Konečný<br>Jakub Seidler<br>Petr Hlaváč | *In the quest of measuring the financial cycle* |
| 4/2015 | Michal Franta | *Rare shocks vs. non-linearities: What drives extreme events in the economy? Some empirical evidence* |
| 3/2015 | Tomáš Havránek<br>Marek Rusnák<br>Anna Sokolova | *Habit formation in consumption: A meta-analysis* |
| 2/2015 | Tomáš Havránek<br>Diana Žigraiová | *Bank competition and financial stability: Much ado about nothing?* |
| 1/2015 | Tomáš Havránek<br>Zuzana Iršová | *Do borders really slash trade? A meta-analysis* |
| 16/2014 | Mark Joy<br>Marek Rusnák<br>Kateřina Šmídková<br>Bořek Vašíček | *Banking and currency crises: Differential diagnostics for developed countries* |
| 15/2014 | Oxana Babecká Kucharčuková<br>Peter Claeys<br>Bořek Vašíček | *Spillover of the ECB's monetary policy outside the Euro Area: How different is conventional from unconventional policy?* |
| 14/2014 | Branislav Saxa | *Forecasting mortgages: Internet search data as a proxy for mortgage credit demand* |
| 13/2014 | Jan Filáček<br>Jakub Matějů | *Adverse effects of monetary policy signalling* |
| 12/2014 | Jan Brůha<br>Jiří Polanský | *The housing sector over business cycles: Empirical analysis and DSGE modelling* |
| 11/2014 | Tomáš Adam<br>Miroslav Plašil | *The impact of financial variables on Czech macroeconomic developments: An empirical investigation* |
| 10/2014 | Kamil Galuščák<br>Gábor Kátay | *Labour force participation and tax-benefit systems: A cross-country comparative perspective* |
| 9/2014 | Jaromír Tonner<br>Jan Brůha | *The Czech housing market through the lens of a DSGE model containing collateral-constrained households* |
| 8/2014 | Michal Franta<br>David Havrlant<br>Marek Rusnák | *Forecasting Czech GDP using mixed-frequency data models* |
| 7/2014 | Tomáš Adam<br>Soňa Benecká<br>Jakub Matějů | *Risk aversion, financial stress and their non-linear impact on exchange rates* |
| 6/2014 | Tomáš Havránek<br>Roman Horváth<br>Zuzana Iršová<br>Marek Rusnák | *Cross-country heterogeneity in intertemporal substitution* |
| 5/2014 | Ruslan Aliyev<br>Dana Hájková<br>Ivana Kubicová | *The impact of monetary policy on financing of Czech firms* |

| | | |
|---|---|---|
| 4/2014 | Jakub Matějů | *Explaining the strength and efficiency of monetary policy transmission: A panel of impulse responses from a Time-varying Parameter Model* |
| 3/2014 | Soňa Benecká<br>Luboš Komárek | *International reserves: Facing model uncertainty* |
| 2/2014 | Kamil Galuščák<br>Petr Hlaváč<br>Petr Jakubík | *Stress testing the private household sector using microdata* |
| 1/2014 | Martin Pospíšil<br>Jiří Schwarz | *Bankruptcy, investment, and financial constraints: Evidence from a post-transition economy* |

## CNB RESEARCH AND POLICY NOTES

| | | |
|---|---|---|
| 4/2014 | Josef Brechler<br>Václav Hausenblas<br>Zlatuše Komárková<br>Miroslav Plašil | *Similarity and clustering of banks: Application to the credit exposures of the Czech banking sector* |
| 3/2014 | Michal Franta<br>Tomáš Holub<br>Petr Král<br>Ivana Kubicová<br>Kateřina Šmídková<br>Bořek Vašíček | *The exchange rate as an instrument at zero interest rates: The case of the Czech Republic* |
| 2/2014 | František Brázdik<br>Zuzana Humplová<br>František Kopřiva | *Evaluating a structural model forecast: Decomposition approach* |
| 1/2014 | Michal Skořepa<br>Jakub Seidler | *Capital buffers based on banks' domestic systemic importance: Selected issues* |

## CNB ECONOMIC RESEARCH BULLETIN

| | |
|---|---|
| May 2015 | *Forecasting* |
| November 2014 | *Macroprudential research: Selected issues* |
| April 2014 | *Stress-testing analyses of the Czech financial system* |

Czech National Bank
Economic Research Department
Na Příkopě 28, 115 03 Praha 1
Czech Republic
phone: +420 2 244 12 321
fax: +420 2 244 14 278
http://www.cnb.cz
e-mail: research@cnb.cz
ISSN 1803-7070