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Implementing the New Structural Model of the Czech National Bank

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Abstract

The purpose of the paper is to introduce the new "g3" structural model of the Czech National Bank and illustrate how it is used for forecasting and policy analysis. As from January 2007 the model was regularly used for shadowing official forecasts, and in July 2008 it became the core model of the CNB. In the paper we highlight the most important and unusual features of the model and discuss tools and procedures that help us in forecasting and assessing the economy with the model. The paper is not meant to provide a full derivation of the model or the complete characteristics of its behavior and should not be regarded as model documentation. Rather, the paper demonstrates how the model is used and how it contributes to policy analysis.

JEL Codes: D58, E32, E58, E47, C53.
Keywords: DSGE, filtering, forecasting, general equilibrium, monetary policy.

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Nontechnical Summary

The new structural model (g3) has been used as the core forecasting tool since July 2008. In this paper, the model and its motivations are described and its forecasting and policy use is illustrated.

The model is a general equilibrium small open economy (SOE) model of the Czech Republic. It is a business cycle model to be used in forecasting and policy analysis, therefore forward-looking expectations are an important part of it. The model is structural and has consistent stock-flow national accounting. Its structure aims to capture the main characteristics of the Czech economy. The economic dynamics in the model result from the interactions of households, firms in individual sectors, the central fiscal and monetary authorities, and their counterparts in the rest of the world. The monetary policy authority in the model operates an inflation-targeting regime and both households and firms are aware of the monetary policy regime operated. Hence, there are no credibility or communication uncertainty issues of monetary policy conduct in the model.

From the theoretical point of view the model follows the New-Keynesian tradition, implying important nominal frictions in the economy enriching the real business cycle dynamics. To capture important stylized facts of an emerging economy, the multisectoral nature of the model and a focus on permanently viewed economic shocks are important ingredients of the model. Trends in sectoral relative prices, real exchange rate appreciation, a high import intensity of exports, imperfect exchange rate pass-through, investment specific shocks, and an increase in trade openness are examples of the model's features.

The core of the paper is a presentation on how forecasting and policy analysis are carried out using the model. The two most important parts of the analysis are an assessment of the current state of the economy and a forecast and scenario analysis. In principle, the consistent structure of the model with economic theory embodied allows for interpretation of the observed economic data.

The assessment of the current state of the economy rests on identifying the structural economic shocks that drive the economy. These shocks imply that there is an economic story behind the observed data, since they must be not only observed, but also interpreted. An important step is to assess how new pieces of information affect and/or modify the assessment of the underlying economic trend. The model is thus used to analyze the effects of news and revisions, while allowing more weight to be put on data with smaller measurement errors, less noise, and fewer revision tendencies. Furthermore, the multivariate nature of the model allows timelier extraction of signals on the true state of the economy.

After the current state of the economy is identified and interpreted, a forecast and scenario analysis are carried out. Scenarios may be formed with respect to the assumed paths of particular economic variables or the way expectations about them are formed. Expectation shocks thus can be accommodated within the framework used. In order to fully understand the dynamics of the forecast or the difference between two successive forecasts, the model can be used to decompose these into individual factors. This is very useful, since quantitative information on how individual economic factors, assumptions, and judgments contribute to the forecast is then available.

In principle, all analytical results and the economic story behind the forecast can be communicated without explicit reference to the model while having the whole apparatus on hand to quantify, interpret, and vary the economic scenarios. As such, the model is a useful tool in the complex process of forecasting and policy analysis.

1. Introduction

The Czech National Bank's (CNB's) forecasting and policy analysis system (FPAS) is an important part of monetary policy conduct. The FPAS relies on a suite of formal economic models and expert judgment. In July 2008 the "g3" model became the CNB's core forecasting tool. However, the model had been regularly used since January 2007 to produce shadow forecasts discussed with members of the board. This paper discusses some issues of the model's implementation into a policy environment.

The CNB relies on a suite of models targeted at different purposes and horizons. For medium-term forecasting and policy analysis, a more structural economic model has been developed. Near-term forecasting (NTF) relies mostly on econometric models and expert judgment. The forecasting process is centered around a *core model*. The CNB's former core model was the Quarterly Projection Model (QPM), a reduced-form New Keynesian gap model with some ad hoc, yet well-motivated, features. A complex description of the QPM and the FPAS can be found in the CNB document edited by Coats et al. (2003).

The QPM had been used since mid-2002 to support the inflation-targeting regime. Due to the good experience with the core model, demand for more structural model-based analysis increased at the bank. To satisfy this demand a new structural model was developed. The new structural model developed follows recent developments in constructing Dynamic New-Keynesian (DNK) models for policy analysis, Christiano et al. (2005) and Smets and Wouters (2007) being important contributions.

Although recent improvements in DNK models in matching stylized facts of the business cycle have been impressive, the actual implementation of the Dynamic Stochastic General Equilibrium (DSGE) type of models into forecasting and policy analysis processes seems to be still in its infancy and many unresolved issues remain. Examples of the use of DSGE models for forecasting and policy making include Kilponen and Ripatti (2006), Murchison and Rennison (2006) or Adolfson et al. (2007).

In this paper we introduce the new structural model of the CNB, internally referred to as the "g3 model", and describe how the model is used in the actual forecasting process. We focus on the main departures from "standard" theoretical models and practices and highlight issues we had to solve in order to use the model in the forecasting process. The implementation of the model and its contribution to policy analysis are the main objectives of the paper. The paper does not intend to give a technical derivation or a complete characterization of all the model's properties.

Although the model has been used in regular forecasting exercises since January 2007, the development of the model and the associated new forecasting and policy analysis system has not stopped. On the contrary, experience gained in real-time forecasting exercises and new theoretical developments are being implemented into the modeling framework.

2. Motivations for modeling choices

The model represents a small open economy (SOE) in its post-transition phase and still undergoing many structural changes. The need was to develop a parsimonious forecasting and story-telling model that would be a *useful tool* for monetary policy analysis and forecasting. The model described here builds upon, extends, and implements into policy use the work by Beneš et al. (2005) and is a result of an ongoing project of the CNB's Macroeconomic Forecasting Division. Technical details of the model structure and derivations are given in Andrle et al. (2007).

The model relies on many standard modeling choices in the field of applied dynamic general equilibrium models, employing a variety of nominal and real rigidities and frictions. The model is tailor-made for the Czech economy, yet many of its design features should be suitable for other small open emerging economies as well.

There are several stylized facts and features of convenience that we want the model to account for, namely:

(i) *a well-defined balanced growth path of the economy,*

(ii) *trends in sectoral relative prices and the evolution of nominal expenditure shares,*

(iii) *import intensity of exports and growth in the trade openness of the economy,*

(iv) *nominal rigidities,*

(v) *gradual exchange-rate pass-through,*

(vi) *the observed level of persistence in selected variables.*

Balanced growth path, trends in relative prices, and nominal expenditure shares

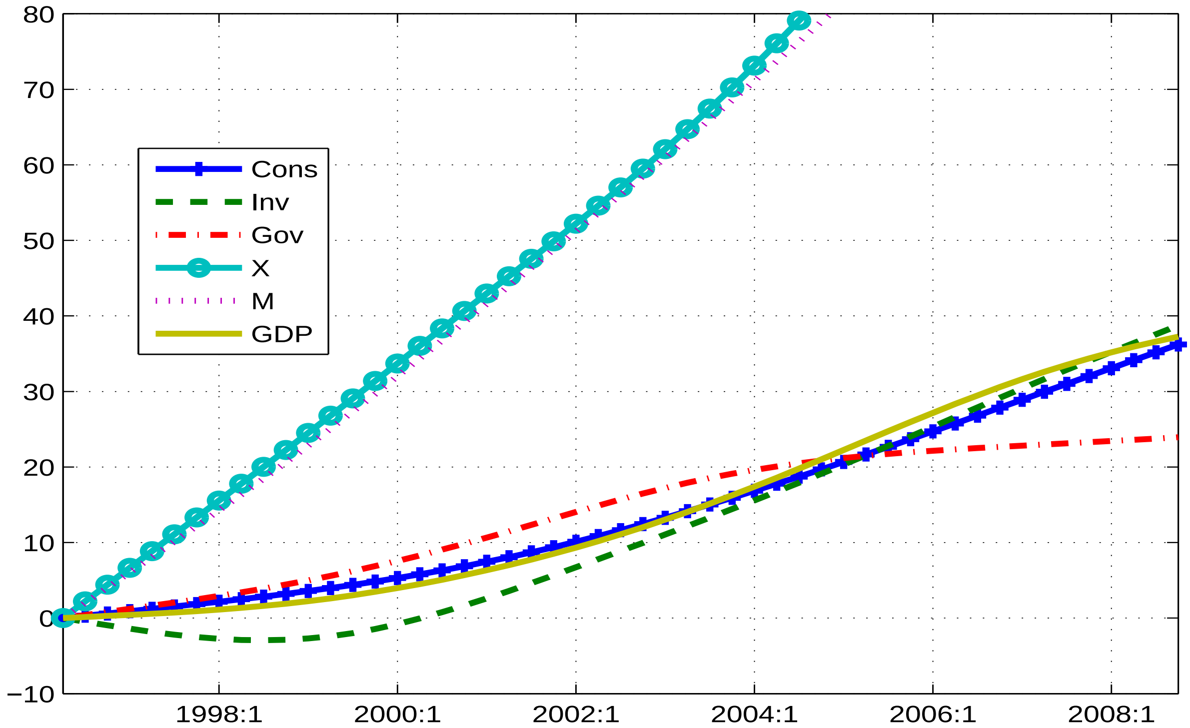
The *balanced growth path* (BGP) specification is important, since we intend to capture both the business cycle and the medium-run behavior of the economy. We think that proper treatment of long-run trends in the model variables is a necessity if the model is to be used in a forecasting process.

When model variables are detrended prior to model analysis, at least two problems can arise in our view. First, ad-hoc filtering of stochastic trends destroys important *trend-cycle interactions* in the data, arising from the fact that permanent shocks spill over to business cycle frequencies. Second, detrending without reflection of common features in the data results in an inconsistent assessment of the data dynamics and severely distorts real-time forecasting and policy analysis with the model. Trend-cycle interactions are especially important in emerging economies, where permanently-viewed large structural shocks arise more often – Aguiar and Gopinath (2004). We view ad-hoc stochastic detrending in the area of DSGE models as a practice fraught with hazards – see Andrle (2008c) for details and further arguments.

Trends in relative prices together with the *development of expenditure shares* are closely related to the balanced growth path of the model. Medium-term expenditure shares in the Czech Republic seem to be gradually approaching the levels in more developed economies. We make an assumption of constant specific nominal expenditure shares in the steady state of the model. On the other hand, we would like to accommodate pronounced *trends in relative prices* among sectors.

Trends in sectoral relative prices, while keeping nominal expenditure shares constant, imply that real quantities must offset the evolution of prices. A good example is the trend in the relative

Figure 1: Real trends (logs, normalized)



Source: Czech Statistical Office, own calculation

price of investment goods with respect to consumption goods – see e.g. Greenwood et al. (1997) or Whelan (2005). The usual definitions of balanced growth path are in line with a single-good economy where the volumes of the variables are co-integrated – see e.g. King et al. (1991).

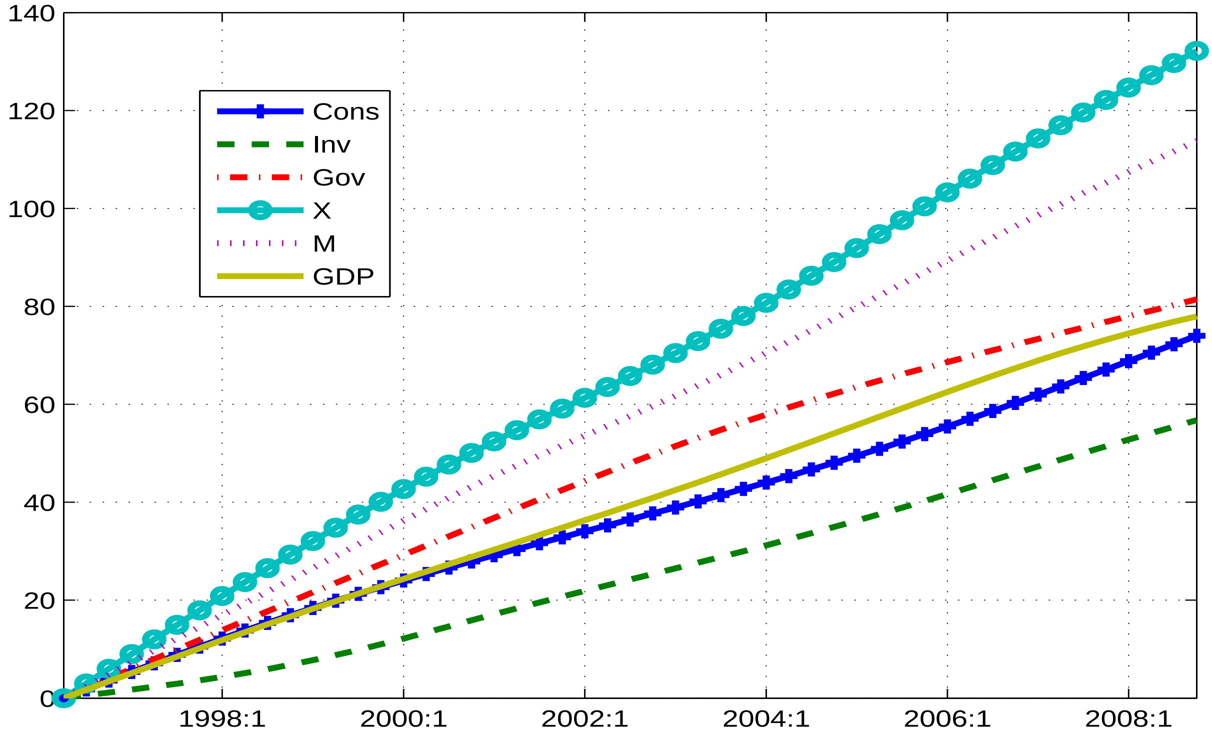
We construct a multisectoral economy and focus on *nominal expenditure shares.* We define a balanced growth path such that the *nominal quantities of macroeconomic variables are co-integrated.* This definition contains co-integration of real volumes as a special case. However, it allows for differential growth of real quantities on the balanced growth path, offset by the evolution of relative prices.

First, the nominal expenditure shares are more stable than the "real" shares. Second, the approach is consistent with *chain-linked National Accounts data* produced for the Czech economy in line with Eurostat recommendations. The chain-linked National Accounts data is a reaction to changes in relative goods prices and constructs real quantities in average prices of the previous year. The real aggregates are not additive by construction and "real expenditure shares" are not informative of resource allocation.

In our view focusing on nominal expenditure shares is both intuitive and *plausible mainly for emerging countries*, but also for many developed ones. Claiming that for some countries "great shares are not that great" may sometimes be a statistical artifact of working with real quantities and disregarding nominal expenditure shares and changes in relative prices.

Fig. 1 presents the normalized trends (HP trends) in the volumes of GDP components, and Fig. 2 depicts the nominal trends in these variables to gain more intuition.

Figure 2: Nominal trends (logs, normalized)



Source: Czech Statistical Office, own calculation

Trade openness and import intensity of exports

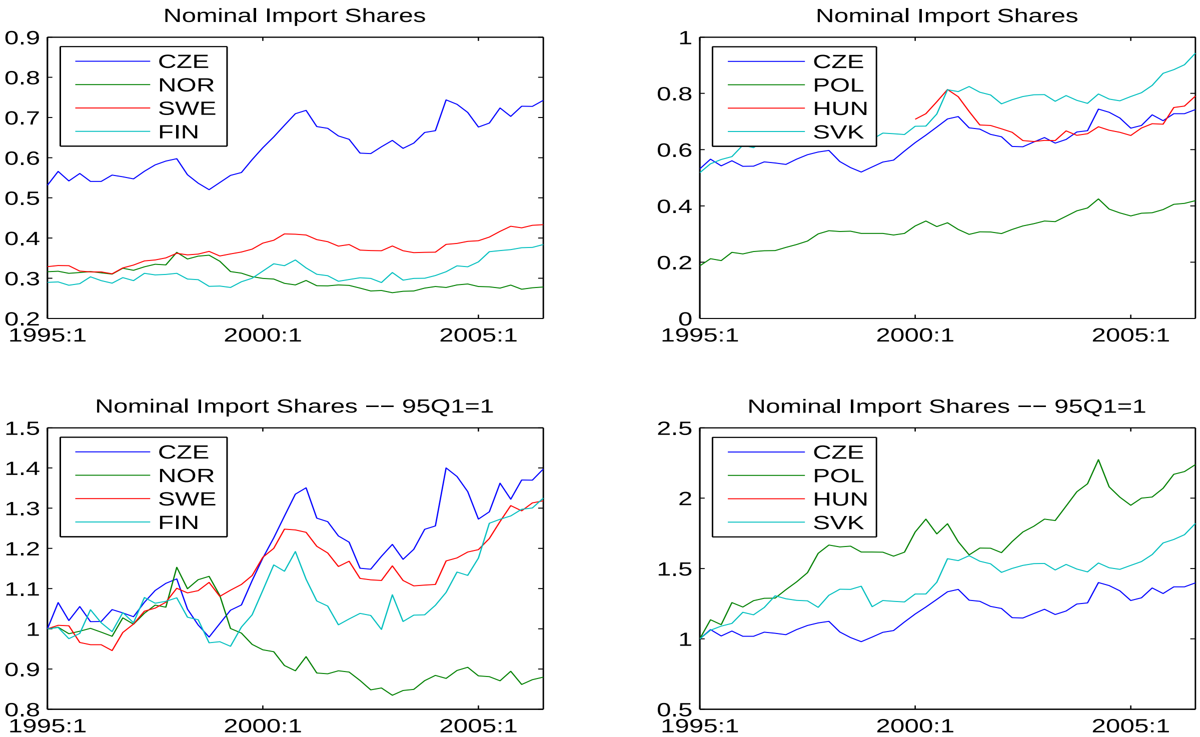
The issue of the *import intensity of exports* is closely related to the overall *increase in trade openness.* Significant excess long-run growth of trade volumes with respect to output growth is inconsistent with the standard balanced growth path definition of a small open economy. A parsimonious solution is needed for a small open economy framework.

It is a well-known stylized fact that a large part of imports are used as components for export goods production. In the Czech Republic the import intensity of exports and increase in trade participation is associated with a massive past inflow of foreign direct investments, many of them green-field investments. Foreign firms are closely linked to parent companies abroad and engage in *vertical specialization*, meaning that they specialize in stages of production.[1]

During the period 1995–2006 the nominal share of imports in value added (trade openness) increased dramatically in the Czech Republic. A similar trend in trade openness can be seen in other former-communist small open economies – Hungary and Slovakia for instance. However, Fig. 3 demonstrates that the increase in the trade openness of the Czech Republic is also comparable to that of Finland or Sweden.[2] Our calculations suggest that on average the increase in trade openness is broadly similar across all the European Union countries. The average increase in EU trade openness is slightly higher than that in the Czech Republic in the last decade after normalization.

[1] In other countries, maquiladora-like trade also results in a high import intensity of exports.
[2] In the case of Norway the nominal import share is affected by terms of trade reflecting an oil-producing country.

Figure 3: Trade openness



Source: OECD Compendium Database, own calculation

The idea that increasing trade openness is an issue only for emerging small open economies is therefore incorrect. However, due to a higher share of trade in value added, the increase in trade openness is more apparent in such countries.

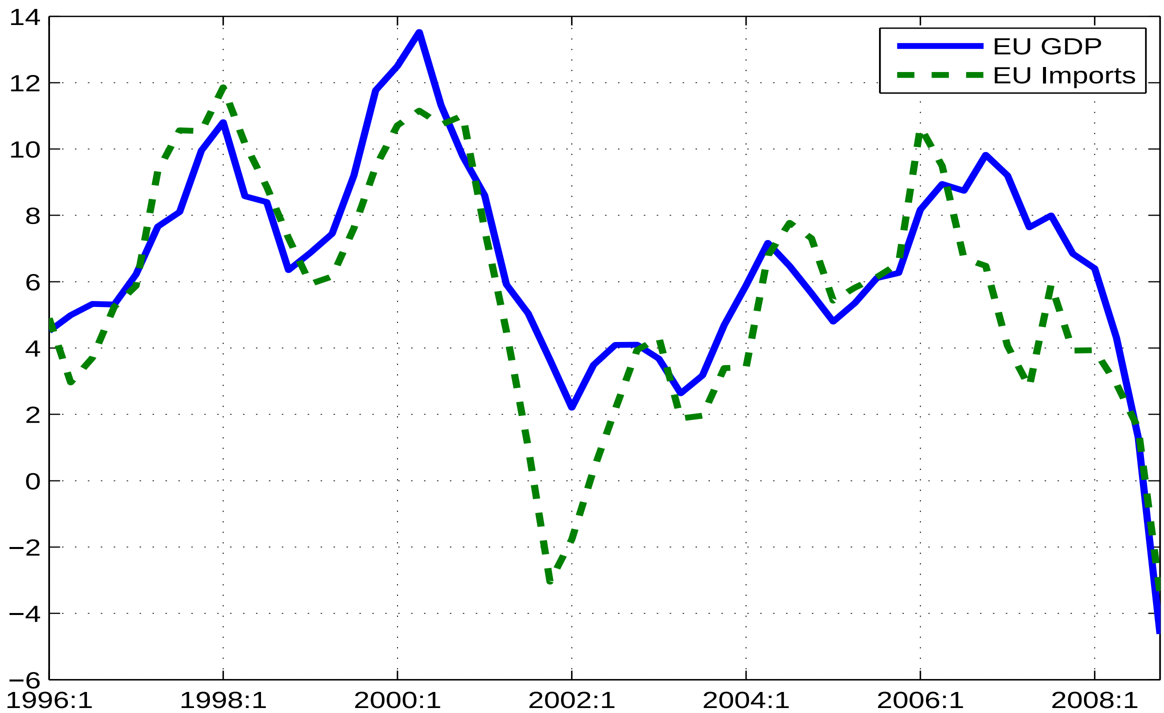
It is a stylized fact that the world import growth rate is on average higher than the growth rate of output. Thus, in the data we observe a different trend behavior of trade volumes compared to value added volumes. At the heart of the problem is the fact that *is not only value added that is traded* in real economies and stylized DSGE models do not feature a proper input-output table structure of economies.

There are many theories why we have witnessed excess growth of international trade volumes with respect to value added during the last 80 years. Our calculations suggest that since World War II there has been a rather stable "rule of four" such that if we multiply year-on-year GDP growth by a factor four, we get a fairly good approximation of trade growth. Fig. 4 demonstrates the "rule of four" using last-decade figures for European Union (EU) GDP and volume of imports in real terms. This confirms that the increase in trade openness is a world-wide phenomenon[3].

The explanation of the phenomenon lies partly in the effect of the globalization-induced decline in overall trade costs due to multiple border crossing of goods, and in increased endogenous participation in foreign trade by domestic firms – see e.g. Hummels et al. (1999) or Ghironi and Melitz (2005). Following the methodology of Hummels et al. (1999) input-output tables

[3] Depending on geographic and data methodology the rule varies within a range of three to four.

Figure 4: Y-o-y growth of EU imports and EU GDP $\times 4$



Source: OECD Compendium Database, own calculation

for the Czech Republic suggest a large degree of vertical specialization and an increase therein, especially in manufacturing and chemicals.

Simply put, the trend in trade significantly exceeds the trend in value added because it is not just value added that is traded and because the concept of *gross production consistent with the national accounts* is absent from the model due to its stylized structure. The multiple stages of creation of total value added are not accounted for in the model structure.

Our assumption of constant nominal expenditure shares in value added is not enough in this case, since it would lead to serious bias in filtering, estimation or forecasting exercises. Contrary to the single-good BGP the nominal-shares framework allows for excess real growth of exports relative to GDP in the long run, offset by the opposite evolution of prices of exports relative to the GDP deflator. Yet it is important to realize that the increase in trade openness is not linked to such developments in the observed relative prices of traded goods.

Thus, the assumption of constant steady-state nominal expenditure shares is inconsistent with the trend in the nominal trade share in output in the data. Since we work with a single country SOE model for forecasting purposes, we cannot model the increase in trade openness in an endogenous way. A richer, multi-country trade structure would be required.

Adopted solution of the trade openness Since we need to work with the observed data, we introduce an *openness technology*, which is an exogenous factor responsible for the increase in trade openness in the model.

To identify the trade openness process we assume that it is a common component of exports and imports of goods and of foreign demand, after we account for the trend in foreign trade implied by sector specific technology and the trend in value added. The openness trend must account for the trend in the nominal share of trade in output and excess growth of trade over GDP.

Using past data the openness technology is identified via *model consistent filtering*, together with other structural shocks in the model. Thus, we avoid ad-hoc detrending of excess growth in Czech exports and imports, since this might seriously modify the business cycle dynamics of the data. Our solution could be viewed as *endogenous detrending* taking care of interactions of the full dynamics of the model and giving the model a chance to interpret the complex dynamics of the data. Technical details are discussed below.

Nominal rigidities, cost of disinflation and exchange rate pass-through

On the aggregate level sectoral prices are sticky. For tractability a time-dependent rigidity is assumed. Each final good producing sector features price stickiness of possibly different degrees. Price stickiness cascading creates desirable interactions between real activity in various sectors and, most importantly, delivers multiple stages of *exchange rate pass-through.*

Gradual exchange rate pass-through is guaranteed not only by multiple price rigidities, but also by an assumption of *local currency pricing.* Domestic importers face foreign prices and exchange rate movements, but their prices are sticky in domestic currency. Similarly, exporters' prices are sticky in foreign currency. These modeling choices allow us to achieve the observed structure of price rigidity and exchange rate effects in import and export prices, investment, and consumption prices.

Nominal wage contracts are also sticky, following a time-dependent scheme. Following the Czech stylized facts, nominal wage stickiness is significantly larger than consumer price stickiness. Prices of intermediate sector producers are less rigid than those of final consumption goods. There is a wedge in the real consumption wage and the real cost of labor that reflects the difference between consumption prices and value added prices, reflected in the terms of trade.

It is also important to realize that the strength of the reaction of prices and wages to shocks is dependent upon the nature of the shock and its persistence and size, since producers are profit-maximizing and forward-looking.

Observed level of real persistence and business cycle dynamics

The model is designed to match stylized facts on the Czech business cycle. Due to the limited information value of the data we focus on major business cycle stylized facts in the literature on small open economies while accounting for the specifics of the Czech Republic.

In order to match the stylized facts on business cycle dynamics we incorporate into the model several mechanisms inducing real rigidities and frictions as well. These include external habit formation of households, investment adjustment costs, and imperfect elasticity of substitution between new and old capital goods. In previous versions of the model we also worked with time-to-build investment projects.

The implementation of credit-constrained or rule-of-thumb households that cannot smooth consumption is an extension considered to match the stylized facts on private and public consumption comovement.

3. Structure of the model

Households

The economy is populated by a continuum of households indexed on the unit interval, i.e., $h \in [0,1]$. Each household consumes all varieties of the consumption final good, rents capital services to the intermediate goods sector, and monopolistically supplies a differentiated unit of labor to an employment agency.

Households are allowed to trade nominal government bonds, but trading in international bonds is delegated to specialized forex dealers. Households own all domestic firms and receive their profits in proportionate share. Apart from net cash-flow transfers from forex dealers they receive lump-sum transfers from the government.

Wage setting follows Calvo contracts. All households face a constant random probability of wage contract duration. In each period a fraction of $1-\xi_W$ households is allowed to reoptimize their wage contracts. Other households follow a simple indexation scheme and update their nominal wage by the previous market-wide gross wage growth.

Since Calvo wage setting induces individual heterogeneity in wage rates and in individual wealth, we introduce a competitive insurance market analogous to Yaari (1965). Owing to the insurance market households choose to pool wage risk, and wage heterogeneity does not affect their shadow value of wealth. Assuming identical preferences and initial wealth endowment we can work with the representative agent paradigm.

Household need to respect the period budget constraint

$$B_t(h)+P_t^C C_t(h)+P_t^J J_t(h) = i_{t-1}B_{t-1}(h)+P_t^K K_{t-1}(h)+P_t^C F_t(h)+\Psi_t(h)+\Phi_t(h), \quad (3.1)$$

where nominal home currency bonds are denoted by B_t and nominal consumption and investment expenditures by $P_t^C C_t$ and $P_t^J J_t$, respectively. The home currency nominal gross interest rate is denoted by i_t, K_t denotes the stock of capital, and P_t^K is the rental rate. Households receive government lump-sum transfers $P_t^C F_t$, labor Φ_t, and dividend income Ψ_t. Consumption prices P^C include indirect taxes, i.e., $P_t^C = (1+\tau_t^C)P_t$.

Labor income consists of net wages and a net insurance transfer,

$$\Phi_t = (1-\tau_t^W)W_t(h)L_t(h) + \begin{cases} 0, & \text{if signal received} \\ V_t(h), & \text{if signal not received,} \end{cases} \quad (3.2)$$

where $W_t L_t$ is nominal wage income adjusted for labor income tax τ_t^W and $V_t(h)$ is the net insurance transfer.

Net cash-flow from forex dealers Ψ_t^{fx} grouped with transfers of pure profits from monopolistic firms in the intermediate, export, import, consumption, investment, and public good sectors are aggregated in Ψ:

$$\Psi_t = \Psi_t^{fx} + \Psi_t^Y + \Psi_t^X + \Psi_t^M + \Psi_t^C + \Psi_t^G + \Psi_t^J \quad (3.3)$$

Investment and capital accumulation

Households own and accumulate the stock of capital goods. The accumulation technology is a special version of intertemporal adjustment costs, following Kim (2003),

$$K_t = \mathcal{K} = [K_{t-1}]^{1-\delta}\,[J_t/\delta]^{\delta} - \frac{\eta}{2}\left(\frac{J_t}{J_{t-1}}\frac{1}{\alpha\alpha^J}\right)^2 K_{t-1}, \quad (3.4)$$

where $\alpha\alpha^J$ denotes gross steady-state investment growth and η is an investment adjustment cost parameter.

This is a special version of a more general specification

$$K_t = \mathcal{K} \equiv \left[\nu(\alpha_K\, K_{t-1})^{\frac{\sigma-1}{\sigma}} + (1-\nu)\left(\frac{J_t}{1-\nu}\right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{3.5}$$

where $\nu \equiv (1-\delta)/(\alpha\alpha_J)$ and setting $\sigma \to \infty$ delivers the standard capital accumulation identity $K_t = J_t + (1-\delta)K_{t-1}$. Allowing for $\sigma \to 1$ leads to the Cobb-Douglas case above.

Welfare

Households strive to maximize their life-time utility function given by

$$\max_{\{C_s,B_s,J_s,W_s\}} U_t(h) = \mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\mathcal{U}\{C_s(h) - \chi\, H_s(h)\} + \mathcal{V}\{1 - L_s(h)\} \right], \tag{3.6}$$

subject to the nominal budget constraint (3.1) and investment accumulation technology (3.4) and subject to downward sloping demand for differentiated labor supply by the employment agency (labor intermediary) and the restriction of Calvo wage contracts. Operator $\mathbb{E}_t$ denotes expectations of all states of nature given up to period t.

External habit is denoted by H_t and follows $H_t(h) = \bar{C}_{t-1} \times \exp\left(e_t^H\right)$, the economy-wide level of previous period consumption, where e_t^H is a habit shock. The separability of consumption and leisure has consequences for the functional forms that we can use in the model in order to obtain a well-specified balanced growth path.

For convenience and future use we define the *nominal pricing kernel of households* using the shadow price of nominal wealth λ_t as

$$\Xi_{t,s} = \mathbb{E}_t \left\{ \beta^{s-t} \frac{\lambda_s}{\lambda_t} \right\} \qquad \text{or} \qquad \Xi_{t,t+1} = \mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \right\}. \tag{3.7}$$

We parametrize the functional forms in a very simple way, using logarithmic utility from consumption and linear (indivisible labor) leisure utility

$$\mathcal{U} \equiv \log \frac{C_t - \chi H_t}{1-\chi} \qquad \mathcal{V} \equiv \kappa\, a_t^L (1 - L_t), \tag{3.8}$$

where a_t^L denotes an economy-wide stochastic process that drives the willingness to participate in the labor market. This nonstationary process induces nonstationarity into hours worked, similarly to Chang et al. (2006). The functional form of the utility of consumption and leisure is carefully chosen with respect to the existence of a balanced growth path.

Wage contracts

The differentiated varieties of labor supplied by individual households are purchased by the employment agency, which costlessly bundles these using the CES aggregator. From the standard profit maximization problem of the agency we get downward sloping demand for household labor, given by

$$L_t(h) = \left[\frac{W_t(h)}{W_t} \right]^{-\varepsilon} L_t. \tag{3.9}$$

As we have already mentioned, the wage setting process follows the Calvo-Yun scheme – see Calvo (1987), Yun (1996), and Schmitt-Grohé and Uribe (2006). Households optimally set their desired wage rate by maximizing their life-time felicity (3.6) subject to the individual labor-demand and indexing scheme for times when not allowed to reoptimize:

$$W_{t+j}(h) = \mathcal{X}_{t,t+j} W_t^*(h) \qquad \mathcal{X}_{t,t+j} = \begin{cases} \prod_{k=0}^{j-1} \Pi_{t+k}^W, & j > 0 \\ 1, & j = 0, \end{cases} \tag{3.10}$$

where Π_t^W is sector-wide wage inflation and W_t^* is the optimally set wage in period t.

Optimal wage setting then follows

$$\left[\frac{W_t^*}{W_t}\right] = \left(\frac{\varepsilon}{\varepsilon - 1}\right) \frac{\mathbb{E}_t \sum_{s=t}^{\infty} (\xi_W \beta)^{(s-t)} \mathcal{V}_{(1-L),s}\, L_s \left(\Pi_t^W / \Pi_s^W\right)^{-\varepsilon}}{\mathbb{E}_t \sum_{s=t}^{\infty} (\xi_W \beta)^{(s-t)} \mathcal{U}_{C,s} \times (W_s / p_s^C)(1 - \tau_s^W) L_s \left(\Pi_t^W / \Pi_s^W\right)^{1-\varepsilon}}, \tag{3.11}$$

where ε is the price elasticity of demand for individual differentiated labor and ξ_W is the Calvo signal parameter.[4]

Where wage setting scheme is expressed in stationary variables and linearized in the vicinity of a stationarized steady state, we can obtain a version of the hybrid Dynamic New Keynesian Phillips Curve

$$\widehat{\Pi}_t^W = \frac{1}{1+\beta} \widehat{\Pi}_{t-1}^W + \frac{\beta}{1+\beta} \widehat{\Pi}_{t+1}^W + \frac{(1-\xi_W)(1-\xi_W\beta)}{\xi_W(1+\beta)} \left[(\widehat{\mathcal{V}}_{(1-L),t} - \widehat{\mathcal{U}}_{C,t}) - \widehat{W}_t^C \right] + \varepsilon_t^W, \tag{3.12}$$

where hatted variables denote deviations from the steady state and $W_t^C \equiv (1 - \tau_t^W) W_t / p_t^C$ is the net real consumption wage. The Phillips wage curve also features a cost push shock ε^W, whose derivation was omitted due to simplicity of exposition.

Since pricing in other sectors follows basically the same setup, *including cost push shocks,* we will not describe the pricing dynamics in monopolistically competitive production sectors in greater detail and refer to this section. All cost-push shocks are restricted to serially uncorrelated processes.

Forex dealers

The international currency bond is delegated to perfectly competitive forex dealers. These are short lived – each one lives for two consecutive periods only and then exits the market. There are thus two overlapping generations of forex dealers in each period. In the first period the forex dealer collects payments from households and invests on international markets. In the second period the dealer transfers net cash-flow back to households and terminates.

Dealers evaluate profits using households' pricing kernel and face quadratic trading costs, governed by parameter ζ_B. As a feature of convenience we assume that the government subsidizes households for trading costs and collects those costs from dealers. The problem of a forex dealer is

$$\max_{\tilde{B}_t^\star} \mathbb{E}_t \left\{ \Xi_{t,t+1} S_{t+1} B_t^\star \tilde{\imath}_t^\star - S_t B_t^\star - S_t \frac{\zeta_B}{2} a_t^B (B_t^\star)^2 \right\}, \tag{3.13}$$

[4] We can also track the wage dispersion dynamics induced by the Calvo model. Up to first-order approximation the wage dispersion does not play any role.

where B^* denotes foreign currency bonds and $\Xi_{t,t+1}$ denotes the nominal pricing kernel of households (3.7).

Trading in international bonds implies a version of the *uncovered interest rate parity* (UIP) condition

$$\mathbb{E}_t \left\{ \Xi_{t,t+1} \frac{S_{t+1}}{S_t} \tilde{\imath}_t^\star \right\} = (1 + \zeta_B \, a_t^B B_t^\star). \tag{3.14}$$

Using the trading cost of adjustment is just one of many possible ways of rendering the model stationary – see Schmitt-Grohé and Uribe (2003) for a lucid discussion of the problem. Apart from the debt-elastic risk premium the model features also an exogenous risk premium shock. In the forecasting version of the model we can also introduce partial sluggishness into the UIP relationship.

3.1 Production sectors

The economy consists of two intermediate goods sectors and four final goods producers. The sectors are monopolistically competitive, instrumentally in order to introduce price rigidities. All firms are owned by households. Profits are rebated to to them and properly treated in the national accounts.

3.1.1 Domestic intermediate goods

There is a continuum of domestic intermediate goods producers $z \in [0, 1]$, who combine the capital stock $K_t(z)$ and labor $L_t(z)$ hired from the household sector on competitive markets to produce a single variety of intermediate good each. All intermediate goods producers possess identical technology and share a common labor-augmenting technology process (share the same information). Producers maximize their profits (i.e., minimize the cost of production) subject to common factor prices, Calvo probability of price adjustment, and demand for individual varieties.

An individual producer employs Cobb-Douglas technology

$$Y_t(z) = \mathfrak{z}_t K_t(z)^{1-\gamma} (A_t L_t(z))^\gamma, \tag{3.15}$$

where A_t and $\mathfrak{z}_t$ are the nonstationary labor-augmenting technology process and the stationary total factor productivity shock, respectively. Due to common production technology, we can define sector-wide production as

$$\int_0^1 Y_t(z) \mathrm{d}z = \mathfrak{z}_t K_t^{1-\gamma} (A_t L_t)^\gamma, \tag{3.16}$$

where the aggregates for capital and labor demanded are defined as $\int_0^1 K_t(z)\mathrm{d}z$ and $\int_0^1 L_t(z)\mathrm{d}z$, implying that the demand of firms for capital services and capital services offered by households are equal, i.e., $\int_0^1 K_t(z)\mathrm{d}z = \int_0^1 K_{t-1}(h)\mathrm{d}h = K_{t-1}$.

All firms minimize the total costs of production $P_t^K K_t(z) + (1 + \tau_t^S) W_t L_t(z)$ s.t. (3.15), which results in marginal (and also average) costs of production

$$Q_t^Y(z) = Q_t^Y = \frac{1}{\mathfrak{z}_t} \frac{[(1 + \tau_t^S) W_t]^\gamma [P_t^K]^{1-\gamma}}{\gamma^\gamma (1-\gamma)^{(1-\gamma)}}, \tag{3.17}$$

and a corresponding relative factor demand. Costs of labor include social contributions $\tau_t^S L_t$. Note that the capital-labor ratio is identical for all producers, since an aggregate market for the capital stock is assumed.

The net cash-flow (profits) of the aggregate intermediate sector may be written as

$$\Psi_t^Y = \int_0^1 p_t^Y Y_t(z)\mathrm{d}z - P_t^K K_t - (1+\tau_t^S)W_t L_t = \int_0^1 (p_t^Y(z) - Q_t^Y)Y_t(z)\mathrm{d}z, \tag{3.18}$$

where we made use of K, L aggregates and the common marginal cost function. Such an expression is important for all sectors during the process of aggregation and the analysis of economy-wide resource constraints. It is clear from (3.18) that a monopolistic markup leads to pure profits in a steady state.

Individual varieties are sold to an intermediate goods bundler that uses the CES aggregator to costlessly produce a composite bundle. The bundler sells the aggregate bundle to the consumption, government, and export producing sectors as inputs for further production.

The optimal pricing problem again gives rise to a New Keynesian Phillips Curve with indexation for the average price level in the intermediate sector. Producers are allowed to set the price optimally conditioned on their view of future market conditions. Note that in our specification the *desired markup* remains constant, but the actual markup fluctuates due to price rigidities.

3.1.2 Imported intermediate goods

For tractability, we assume a continuum of countries in the World, one of which is Home country. In each country there is a mass of importers and exporters. Importers produce costlessly a variety of differentiated import goods using a common CES technology. Each firm imports a CES aggregate bundled by "International Trading Agency" using all world varieties. National exporters thus compete only within the country. Aggregate bundles then compete among countries.

Importers share identical production technology and common technology parameters and trends, thus

$$N_t(i) = a_t^N \left[\int_0^1 o_t(f)^{\frac{\theta-1}{\theta}}\mathrm{d}f\right]^{\frac{\theta}{\theta-1}}, \tag{3.19}$$

where $o(f)$ is the CES bundle from the f-th country International Trading Agency and $\theta > 1$ is the elasticity of substitution between each pair of bundles from different countries. Here a_t^N is a stationary stochastic shock. Note that $o(f)$ itself is a CES bundle, i.e.,

$$o_t(f) = \left[\int_0^1 x_t(\tilde{x}, f)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}. \tag{3.20}$$

Because of the same production technology, we define sector-wide imported intermediate goods production as

$$\int_0^1 N_t(i)\mathrm{d}i = \int_0^1 a_t^N \left[\int_0^1 o_t(f)^{\frac{\theta-1}{\theta}}\mathrm{d}f\right]^{\frac{\theta}{\theta-1}}\mathrm{d}i. \tag{3.21}$$

The cost minimization problem of importers implies

$$Q_t^N = Q_t^N(i) = \frac{S_t p_t^o}{a_t^N} = \frac{S_t}{a_t^N}\left[\int_0^1 \left(p_t^\star(\tilde{x}, f)^{1-\varepsilon}\mathrm{d}\tilde{x}\right)^{\frac{1-\theta}{1-\varepsilon}} \mathrm{d}f\right]^{\frac{1}{1-\theta}}. \tag{3.22}$$

Individual importers follow Calvo pricing subject to signal probability $(1-\xi_N)$ and demand for their production by the imported goods bundler. The indexation scheme is identical to the one in other sectors. The bundler then resells the aggregate imported bundle N_t to the consumption, investment, and export sectors

$$N_t = N_t^C + N_t^X + N_t^J. \tag{3.23}$$

3.1.3 Consumption final goods

Consumption final goods are produced by monopolistic producers, who utilize the imported bundle of goods together with the intermediate domestic good to create consumption goods.

Individual producers have identical production technology,

$$\int_0^1 C_t(v)\mathrm{d}v = w_t^C\left[\omega_C^{1/\eta_C}\left(\frac{N_t^C}{a_t^X}\right)^{\frac{\eta_C-1}{\eta_C}} + (1-\omega_C)^{(1/\eta_C)}\left(Y_t^C\right)^{\frac{\eta_C-1}{\eta_C}}\right]^{\frac{\eta_C}{\eta_C-1}} \tag{3.24}$$

where w_t^C is a common technology stochastic shock and a_t^X is a reflection of an export specific technology shock. Again, N_t^C and Y_t^C are the inputs of intermediate imported and domestic goods employed by consumption sector.

The corresponding nominal marginal cost can be written as

$$Q_t^C = \frac{1}{w_t^C}\left[\omega_C\left(P_t^N a_t^X\right)^{(1-\eta_C)} + (1-\omega_C)\left(P_t^Y\right)^{(1-\eta_C)}\right]^{\frac{1}{1-\eta_C}} \tag{3.25}$$

with the corresponding demand for factors of production as

$$\frac{N_t^C}{a_t^X} = \omega_C\left(\frac{P_t^N a_t^X}{Q_t^C}\right)^{-\eta_C} C_t w_t^{C\,(\eta_C-1)} \qquad Y_t^C = (1-\omega_C)\left(\frac{P_t^Y}{Q_t^C}\right)^{-\eta_C} C_t w_t^{C\,(\eta_C-1)} \tag{3.26}$$

Note that the imported goods N_t^C are already deflated for openness technology, which is used only in the filtering problem. Furthermore, we introduce a time-varying productivity process a^X, increases of which make the use of imported good less productive and effectively more expensive. This can also be seen from (3.25).

Prices of consumption goods are sticky, driven by the Calvo signal probability $(1 - \xi_C)$ and full indexing on past inflation. The pricing decision is, again, analogous to the wage-setting problem of households.

In flexible price equilibrium the price is equal to the markup over nominal marginal costs, hence $P_t^C(v) = \mu Q_t^C$.

Regulated prices Regulated (administered) prices still form a very important part of CPI index dynamics in the Czech economy. Since the CNB inflation target is specified using the headline CPI including regulated prices, these are often a topic of discussion between policy-makers and forecasters. The requirement of explicit treatment of administered prices directly in the model follows immediately.

The treatment of regulated prices changed several times during 2007, when the model was used for shadowing the forecasts. The lesson learned is that in a structural model *regulated prices require structural interpretation.* As opposed to the QPM model, specified in gaps and growth rates, in the g3 model relative prices matter. We have to accommodate the fact that headline CPI with regulated prices and the "net inflation" price index[5] are not co-integrated in levels over their history. Since the relative price of regulated and non-regulated prices matters in the model we need to know its steady-state value. However, we can only make the assumption that the steady-state growth rate of both prices is identical, assuming full deregulation in the steady state.

Using a specification with a pre-determined steady-state relative price is problematic. All agents would know the steady-state value and after many years of (on average) increases in regulated prices they would assume a correction. Thus, we adopted a specification allowing headline CPI and net inflation to diverge in levels, specifying a steady state in growth rates only.

We explicitly assume that all agents consume two consumption goods baskets – regulated and "market" goods. These consumption goods sectors are *identical* in terms of cost structure and pricing decisions. However, the utility aggregator of households contains *regulated shocks* a_t^R making regulated goods relatively costlier. Due to our specification the regulated shock affects both prices and quantities and is of a permanent nature. Thus, it induces a trend in the relative price of the net and headline CPI basket, while keeping the nominal share of consumption in value added constant in the steady state as required.

After the regulated shock returns to its steady state (i.e., zero growth), regulated price effects and regulated goods virtually disappear from the model and all consumption goods become market goods. That is a very intuitive result. The actual development of regulated prices is enforced on the model using a simple bridge equation that links the exogenous path of regulated prices with regulation shocks.

Regulated prices thus affect the behavior of the whole economy and monetary policy conduct. Importantly, given a pre-determined path of regulated prices the central monetary authority can exercise its influence via net inflation of market goods only. A rise in regulated prices thus leads to downward pressures on net inflation in the case of headline CPI inflation targeting.

In future versions of the model the treatment of regulated prices may change to improve the structural interpretation of their development and endogenous feedback with exchange rate and energy prices.

3.1.4 Export goods sector

Export-goods-producing firms use the same inputs as consumption producers. Firms are monopolistically competitive and share identical technology

$$\int_0^1 X_t(e)\mathrm{d}e = w_t^X \left[\omega_X^{1/\eta_X} \left(N_t^X\right)^{\frac{\eta_X-1}{\eta_X}} + (1-\omega_X)^{(1/\eta_X)} \left(Y_t^X a_t^X\right)^{\frac{\eta_X-1}{\eta_X}}\right]^{\frac{\eta_X}{\eta_X-1}} \tag{3.27}$$

[5] Net inflation is defined as CPI inflation with a basket of so-called administered or regulated goods extracted. Although these goods are not always regulated in the strict sense, they are subject to administrative, mostly deregulation measures of the government.

Here, the time-varying productivity a^X enters as well, making intermediate domestic goods more effective and cheaper in the production of exports. The production structure implies the following marginal costs

$$Q_t^X = \frac{1}{w_t^X} \left[\omega_X \left(P_t^N\right)^{(1-\eta_X)} + (1-\omega_X)\left(P_t^Y / a_t^X\right)^{(1-\eta_X)} \right]^{\frac{1}{1-\eta_X}} \tag{3.28}$$

and the corresponding demand for inputs follows.

The pricing behavior is analogous to other sectors with price rigidities, with Calvo signal probability $(1 - \xi_X)$. The only and important difference is that domestic exporters are sticky in *foreign currency.*

Stochastic productivity a^X drives a wedge between the real growth rate of trade (exports, imports) and value added. Symmetrically, it drives a wedge between GDP deflator growth and growth of the import and export deflators. The permanent effects of export-specific shocks thus allow for consumption-based real exchange rate appreciation in the long run.

We assume that importers in other countries are modeled in an analogous way as importers in Home country. Due to CES aggregation and cross-country competition demand for domestic export goods, production is

$$X_t = \left(\frac{P_t^X}{P_t^\star} \right)^{-\theta} N_t^\star, \tag{3.29}$$

implying that in the case of a unit relative price the demand for exports grows in line with foreign demand. The variable $N_t^\star$ is already deflated for *trade openness* technology, as well as X_t.

By foreign demand we mean the volume of world trade as expressed by imports of the EA14. Such a time series is, however, only a proxy for the true or effective foreign demand for Czech export goods. To account for changes in the composition of demand due to preference shifts, for instance, we define $N_t^\star = \tilde{N}_t^* \times a_t^Q$. Here, a_t^Q is a technology process allowing for the incorporation of expert judgment on the *quality* and *composition* of foreign demand. Then, $\tilde{N}_t^*$ is the actual series for EA14 imports.

Although this treatment of foreign demand may seem somewhat arbitrary, we think there is an important economic story behind such a short-cut solution. We can identify historical periods where Czech exports were booming despite slack observed (proxy of) foreign demand and losses in price competitiveness. During these periods, certain EU countries switched to Czech goods, considering them to be of good quality, yet cheaper. However, the data will not fully reveal this kind of switch.

Using the historical data and filtering techniques we identified the model-consistent evolution of "quality technology". Where sectoral experts in the forecasting department provide a sound justification for export goods behavior difficult to capture by the model, we can use quality technology to adjust for such behavior.[6]

3.1.5 Investment goods sector

The current version of the model assumes that capital goods are produced using imported goods only. The reasons are to allow for investment booms without immediate spillover into domestic

[6] A proper treatment of quality changes in line with the quality ladder theory is being prepared for a future version of the model.

value added, and the fact that the investment sector is very import intensive. Although this specification is an extreme case, sectoral experts and national accounts data support this stylized view to a great extent, despite the non-negligible role of construction. The truth also is that the investment decision in the model is rather sensitive to interactions between the marginal *Tobin's q* and the price of new capital goods, and hence foreign prices and the exchange rate.

Individual producers share a common technology

$$\int_0^1 J_t(i)\mathrm{d}i = a_t^J \frac{N_t}{a_t^X}, \tag{3.30}$$

where a^J is the aggregate investment-specific technology trend. Demand for inputs follows, together with the sector-wide marginal cost of production

$$Q_t^J = Q_t^J(i) = \frac{a_t^X}{a_t^J} p_t^N. \tag{3.31}$$

Both processes are non-stationary. Increasing a^X fosters larger imports of goods in order to produce given amount of investment goods.

As opposed to "trade technology" a^X, investment-specific productivity affects the aggregate growth of value added, and thus of all real variables in the model. This is because investment-specific technology affects production in domestic intermediates via capital stock accumulation.

Pricing behavior in investment-goods-producing firms is again similar to other monopolistic sectors – prices are formed using markup to marginal costs and follow a Calvo scheme with resetting signal $(1 - \xi_J)$. The pricing can again be understood as a New Keynesian Phillips Curve.

3.1.6 Public spending goods

We assume complete home bias in public goods production. The only input to production is the domestic intermediate goods bundle. The assumption is very close to reality, as can be seen from national accounts data.

All producers possess identical technology

$$\int_0^1 G_t(q) = a_t^G Y_t^G, \tag{3.32}$$

with

$$Q_t^G = Q_t^G(q) = p_t^Y / a_t^G, \tag{3.33}$$

where a_t^G is the sector-wide technology process. The demand for Y^G is obvious.

Again, pricing behavior is virtually identical to other sectors. Calvo signal probability is driven by $(1 - \xi_G)$.

3.2 Central monetary and fiscal authority

The model operates under a cashless limit framework. Seigniorage revenues are omitted and a direct accounting link between the government and the central bank is absent.

3.2.1 Monetary policy

Monetary policy is credible. The central bank implements a regime of *inflation targeting* (inflation forecast targeting) and follows the following interest rule

$$\log i_t = \rho_M \log i_{t-1} + (1 - \rho_M)[\log \bar{\imath}_t + \psi \log \widehat{\Pi}_{t+4}] + e_t^M, \tag{3.34}$$

where $\log \widehat{\Pi}_t$ is the deviation from the inflation target and $\bar{\imath}_t$ is the neutral nominal interest rate. Currently it is understood to be the steady-state real rate of interest augmented for the inflation target. For simulation and filtering purposes we also introduce a monetary policy shock e_t^M.

The official inflation target of the Czech National Bank is headline CPI, including regulated prices less the immediate influence of changes in indirect taxation. We implement such a measure into the model. The monetary authority in the model targets the deviation of year-on-year CPI inflation from its target *four periods ahead.*

3.2.2 Fiscal authority

The government collects taxes and fees (transaction costs), distributes lump-sum transfers, and consumes public-spending goods. There is no productive or utility-enhancing spending in the model. Public debt accumulation is allowed for and the government obeys a period budget constraint given by

$$B_t^G = i_{t-1} B_{t-1}^G + p_t^G G_t + p_t^C F_t - \frac{\zeta_B}{2} S_t \tilde{B}_{t-1} - (\tau_t^W + \tau_t^S) W_t L_t - \tau_t^C p_t^{C'} C_t. \tag{3.35}$$

Note that the period budget identity does not constitute a *fiscal policy rule*. The rule, however, must always be specified.[7]

In the current version of the model it is assumed that the fiscal authority guarantees its intertemporal solvency via adjustment of public transfers. The dynamics of government spending are either exogenous or linked to private consumption or output. In actual forecasting exercises, one can make use of the institutional setup in the Czech Republic, where legally binding *expenditure ceilings* have been introduced, and impose these in periods where they are known.

Empirical research of the fiscal policy effects on the Czech economy is scarce, the work by Radkovský (2006) being a prominent exception. However, the results of the analysis seem ambiguous. In parallel with the stylized facts about fiscal policy effects, *liquidity-constrained* households are considered to be a useful extension of the model to allow for plausible demand effects of fiscal policy. However, a particularly detailed treatment of fiscal policy and tax issues is not a priority in the g3 model.

3.3 National accounting

An important feature of the new structural model is model-consistent (national) accounting of all stock and flows. Although this is rather standard, we briefly outline the main relationships to demonstrate the usefulness of postulating a structural model.

Consolidating the budget constraints of the economy we obtain the national resource constraint

$$S_t B_t^* = S_t B_{t-1}^* \tilde{i}_{t-1}^\star + GDP_t - AB_t, \tag{3.36}$$

[7] In a Ricardian economy with lump-sum transfers the debt rule is recursive if lump-sum transfers are used to ensure solvency. However, there is a tacit assumption that all agents believe the government will not breach the intertemporal resource constraint.

or, equivalently,

$$S_t B_t^* = S_t B_{t-1}^* \tilde{i}_{t-1}^\star + (P_t^X X_t - Q_t^N N_t), \tag{3.37}$$

where GDP and AB stand for nominal gross domestic product and nominal absorption, respectively. Obviously, $P_t^X X_t - Q_t^N N_t$ stands for the trade balance and (3.37) describes the *current account* and net foreign debt law of motion.

Using the expenditure-based approach, gross domestic product is *defined* as

$$GDP_t = P_t^C C_t + P_t^J J_t + P_t^G G_t + P_t^X X_t - Q_t^N N_t \tag{3.38}$$

and domestic absorption is defined by

$$AB_t = P_t^C C_t + P_t^J J_t + P_t^G G_t. \tag{3.39}$$

Using the *income structure* of gross value added, we can decompose GDP into

$$GDP_t = P_t^K k_t + (1 + \tau_t^S) W_t L_t + \tau_t^C P_t^{C'} C + \Psi_t, \tag{3.40}$$

or, equivalently,

$$\begin{aligned} GDP_t =& Q_t^Y Y_t + (P_t^{C'} - Q_t^C) C_t + (P_t^X - Q_t^X) X_t + (P_t^J - Q_t^J) J_t + (P_G - Q_t^G) G_t \\ &+ (P_t^N - Q_t^N) N_t + (P_t^Y - Q_t^Y) Y_t + \tau_t^C P_t^{C'} C_t \end{aligned} \tag{3.41}$$

An inherent property of the model is that there is no single-good counterpart of real value added (GDP) in the model. The reason is that each sector has its own price level, rendering the single-good GDP concept inapplicable. In order to obtain the *growth rates* of real GDP, we have to use chain-weighted indices or some sort of approximation (Divisia approximation of the ideal Fischer index).

Given the structure of the model, it should not be surprising that the main source of value added is in the domestic intermediate sector, produced by the services of labor and capital. The value added in the other final good sectors comes from monopolistic profits only, since these sectors work mainly as aggregators and distributors.

Note also that we define GDP in nominal *market* prices, i.e., including VAT in the consumption sector, and adjust the related identities accordingly.

Figure 5: Flow of goods & services in the model

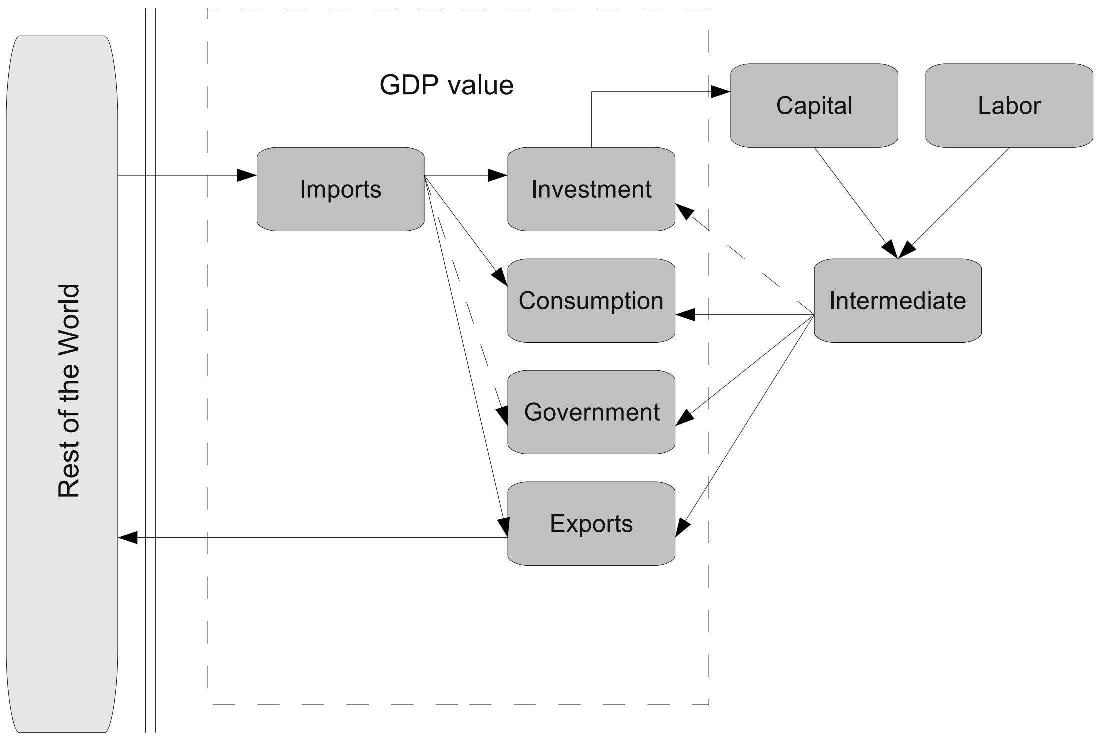
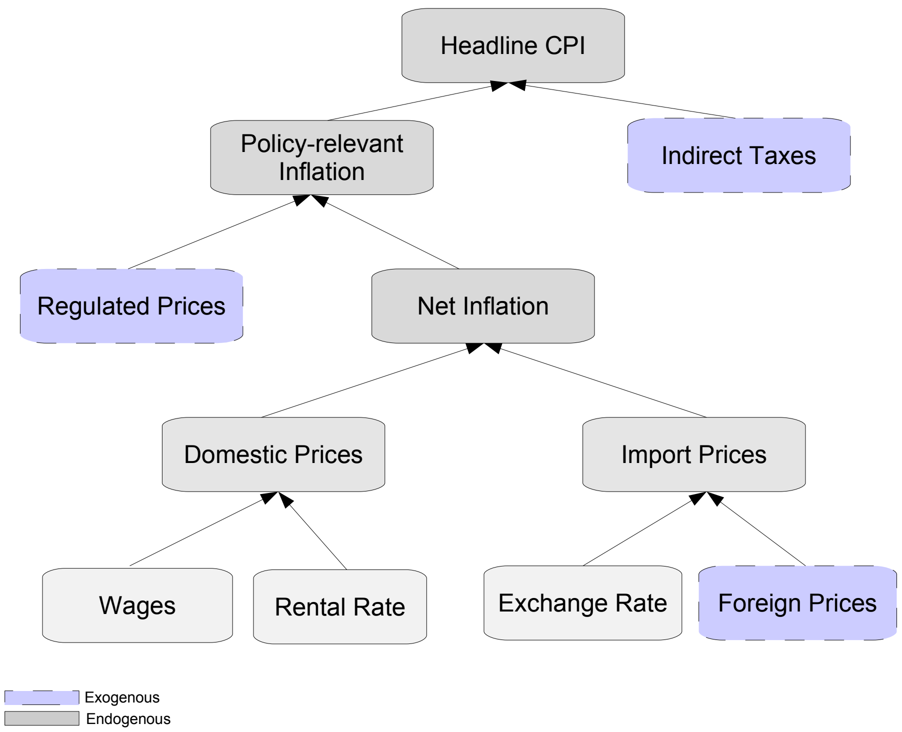


Figure 6: Headline CPI components ("price tree")



4. Balanced growth path (BGP)

The balanced growth path determines the steady-state growth of the model economy. It is defined using exogenous forcing processes – by technology or preference structural shocks.

Since we do not apply ad hoc detrending procedures to the observed data, we must pay great attention to the model's long-run equilibrium. The balanced growth path definition is an important part of the model and significantly affects its simulation and forecasting properties.

Using a nonstationary model also allows us to work explicitly with multiple transitory, yet persistent, and permanent structural shocks and investigate their impact on business cycle dynamics. In this section we introduce the structure of our model's BGP and discuss its implications and how it relates to forecasting.

4.1 BGP definition

We define a balanced growth path as a long-run solution of the model where all variables are either constant or grow at a unique constant pace. The pace of the variables may not necessarily be a common one even for real quantities. *Nominal expenditure shares are constant along the balanced growth path.*

There are two categories of stochastic trends in the model – real and nominal ones. There is one nominal trend – a steady-state rate of inflation. Since there are multiple real stochastic trends, trends in relative sector prices emerge and *technology trends interact among themselves.*

We have six major permanent technology processes in the model – investment-specific technology a^J, public goods sector-specific productivity a^G, trade productivity technology a^X, a willingness-to-work preference process a^L, quality view technology a^Q, and a labor-augmenting technology process A. Of them, A, a^X and a^J are the most important ones.

The calculation of the equilibrium rates of growth for individual variables involves careful inspection of cross-restriction and choosing plausible functional forms and/or model structure. The existence of a balanced growth path of the model is proved in Andrle et al. (2007), where all other details are described.

Owing to the BGP specification an *aggregate implied* stochastic trend arises as a function of labor-augmenting A, investment-specific a^J and willingness-to-work a^L technology processes and determines steady-state growth of value added. The intuition is straightforward.

The implied aggregate rate of growth can thus be expressed as

$$\dot{Z} \equiv [(1-\gamma)/\gamma]\dot{a}^J + \dot{A} - \dot{a}^L. \tag{4.42}$$

Since $\dot{Z}$ is also the growth of value added in the steady state, we use it as a main reference variable when we stationarize the model. This is a very convenient way of economizing on notation and enhancing intuition. Value added price deflator steady-state growth is denoted by $\dot{P}^Y$.

The use of $\dot{Z}$ enhances intuition and can be regarded as the main real trend of the economy, since the equilibrium growth rates of many variables can be expressed as more or less complicated relations to these value added trends. For instance, the investment growth rate is $\dot{J} = \dot{Z} + \dot{a}^J$, while the trend in the relative price of investment can be seen from $\dot{P}^J = \dot{P}^Y - \dot{a}^J$. Since there is no consumption sector-specific trend, we have $\dot{P}^Y = \dot{P}^C$. From these relations we can immediately see the implied *constancy of expenditure shares*, since obviously

$$\left(\dot{P}^J + \dot{J}\right) = \dot{P}^Y + \dot{Y} = \dot{P}^Y + \dot{Z}. \tag{4.43}$$

Such a specification of the BGP is consistent with the partial evidence in Fig. 1 and Fig. 2, where the real and nominal normalized trends of GDP components are depicted. The issue of trade openness is solved below. Note that we assume investment and government spending steady-state growth in real terms to be identical to value added, implying $a^J = a^G = 0$.

We *stationarize the whole model* using the individual variables' steady-state rates of growth. A summary of all the variables' growth rates can be found in Andrle et al. (2007). Although the model can be solved in a non-stationary form, we decided to stationarize it anyway. For a *medium-sized* model the benefits of careful stationarization of the model outweigh the costs. Stationarizing the model makes us better understand the model dynamics, is less error-prone, and expands the variety of tools (and solution techniques) we can use with the model. Note, however, that for the filtering problem we use non-stationary observables and define the measurement equations in terms of these non-stationary variables.

Transitory notion of the BGP Given that the Czech Republic is an emerging country converging toward the European Union countries, our model definition of the BGP is a "transitory BGP". The model converges toward its calibrated BGP, which is linked to the rest of the world's economic development, yet we do not assume the BGP to be set once and for ever. The transition process of an emerging economy toward a more developed one is not explicitly modeled. This is a feature of convenience, since the business cycle model converges to its steady state at a relatively rapid pace.

The steady-state growth rate of the economy is currently calibrated to 5% annually, which seems plausible in the medium term for the Czech economy. The calibration may change in response to development of the global economy. To bring the model into line with the observed data, we introduce a wedge into interest rates, capturing the *risk-free-rate and equity-premium* puzzles. The model is thus dynamically efficient and the capital-labor ratio corresponds to rather high real yields in the profit sector, while allowing nominal money-market interest rates to be low.

We also allow for a permanent *Baumol-Bowen effect* by productivity overhaul in trade sectors with respect to other sectors. Our setting can be mapped into the otherwise standard tradables-nontradables specification in a steady state. Considering the productivity developments in Rest of the World the *Harrod-Balassa-Samuelson effect* is allowed for in the medium run, implying real appreciation of the real exchange rate calculated in consumer prices.

4.2 Trade openness along BGP

The balanced growth path indicated above would also imply a constant expenditure share of exports and imports of goods and services in value added. From Fig. 2 it is apparent that these are not constant.

The issue of increasing trade openness cannot be modeled in a small open economy framework if one uses a single variable to express foreign demand. We have already argued that increasing trade openness is not restricted to the Czech Republic and virtually all countries are witnessing the same process.

Since we attempt to treat the trend behavior of the model in consistent way, we introduced an *openness technology* a^O to account for trend in the nominal expenditure share of trade in value added. Agents in the model are assumed to view all trade quantities already deflated by a^O_t and thus it is invisible to them; they pay just for the deflated quantity.

The openness technology trend a^O is thus used in relating the model to the data. It is used when defining the *measurement equations* in the *filtering problem*. The volumes of exports, imports, and foreign demand are augmented for this stochastic trend, which allows us to identify *trade openness* in the history and separate it from other parts of growth.

Were it not for the openness trend a^O, the volume of exports, imports and foreign demand would have to be trending by the "aggregate" trend Z and trade technology a^X. Thus, in relation to the observed time series we impose the following structure of long-run growth

$$\dot{N} = \dot{X} = \dot{Z} + \dot{a}^X + \dot{a}^O \qquad \dot{N}^\star = \dot{Z} + \dot{a}^X + \dot{a}^O. \tag{4.44}$$

Due to the cross-restriction on $N, X,$ and $N^\star$ the openness technology is well identified for the filtering problem as a common component of these. The evolution of openness technology identified using past data provides a valuable indication of the future projection needed during the forecast period. We label our solution for openness growth as *endogenous detrending,* since it is not completely structural, but allows us to exploit the model's cross-restrictions and overall dynamics in identifying stochastic trends in the economy.

The state-space form looks as follows

$$X_t = AX_{t-1} + R\varepsilon_t \tag{4.45}$$
$$Y_t = BX_t + CY_t^O + S\xi_t \tag{4.46}$$
$$D(L)Y_t^O = \eta_t, \tag{4.47}$$

where X_t is a vector of state variables (model variables), Y_t is a vector of measurement variables, and Y_t^O is a vector of auxiliary variables, in our case including openness only. A loading matrix C captures the impact of auxiliary variables on selected observables. Note that the measurement variables can be non-stationary, i.e., we are measuring the variables in levels.

5. Calibration, testing, and model analysis

The model is *calibrated* and our approach to calibration is very eclectic. The term calibration should be understood in a very broad sense, since we use a variety of tools to achieve model behavior consistent with our prior beliefs, stylized facts, and observed data dynamics.

The use of Czech data in the model calibration serves a key and a limited role at the same time. There are two reasons for this. First, the macroeconomic time series at quarterly frequency are quite short – 1996:1–2008:4. Second, not all the available data can be viewed as supportive of a relatively simple and standard macroeconomic model. The reason is that the economy is still in its transition or post-transition period. Some pieces of data cannot be viewed as reliable. Still, we devote great care to data analysis.

In our model calibration we follow the minimal econometric approach to DSGE models of Geweke (2006). We are aware of the model's stylized nature and its inherent misspecification. We focus mainly on the *population properties* and *story-telling potential of the model.* Our ongoing exploration of identification issues confirms the conclusions of Canova and Sala (2006) that one must be cautious when formal estimation techniques are used. It is a well-known fact that mapping from deep to reduced-form parameters may itself cause serious identification problems, even when ideal population data are available. The identification of model parameters was explored by inspecting properties of the Fisher information matrix, see Rothemberg (1971), of the model using the singular value decomposition to locate unidentified or weakly identified parameters.

Great care has been devoted to obtaining an analytical recursive identification of the stationarized steady state of the model. Apart from enhanced intuition and numerical ease, the analytic steady state allows us to work transparently with setting the long-run growth of the main variables and "great ratios". Furthermore, we divide the parameters into two groups. The first group consists of parameters determining the steady state of the model, while the second group contains parameters driving the short-run dynamics.

We inspect the model using (i) *impulse-response analysis* with respect to both unanticipated and anticipated shocks, (ii) *model-consistent filtering of structural shocks* and shock decomposition of historical data, (iii) *forecast error variance decomposition*, (iv) *time and frequency-domain analysis of the model's moments*, and (v) *recursive filtering and forecasts,* to name the most commonly used methods.

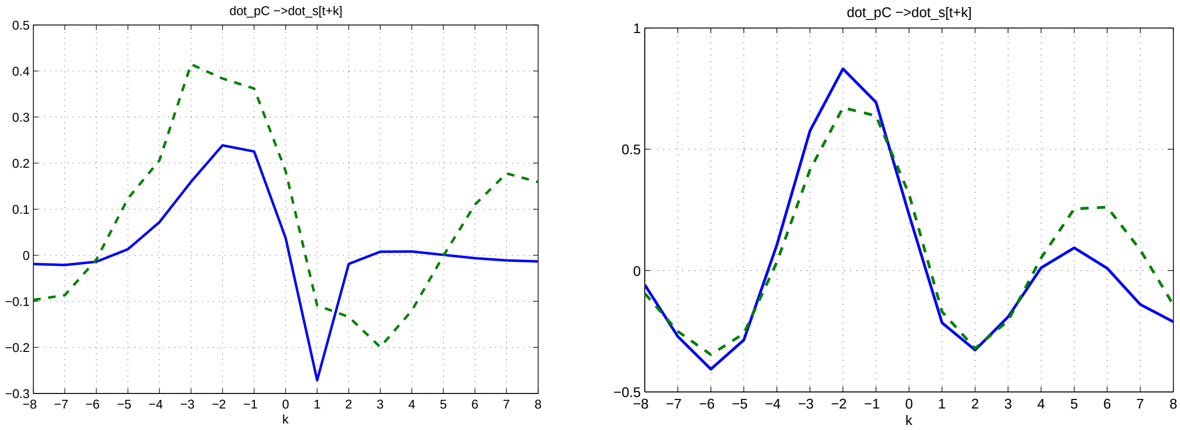
Many of these fairly common and standard methods offer important insights into the workings of the model. With respect to impulse-response analysis we would like to highlight the importance of understanding the response to anticipated shocks in case one is considering using anticipated shocks in the forecasting exercise.

5.1 Population moments of the model

We focus on the population properties of the model using both the time- and frequency domain views. Different parametrizations are inspected together with parametric estimates of the sample and population moments of the Czech data.[8] We also decompose the covariance structure of the model into individual structural shocks to judge the importance of individual shocks for the magnitude and direction of cross-correlations (*conditional moments*).

[8] Although we focus on the population moments of the model, we present point estimates only. The bootstrapped confidence intervals using the available data are usually large.

Figure 7: Correlation of CPI inflation and exchange-rate growth rate



(A) (B) – frequency-specific

Note: solid line – model, dashed line – VAR point estimate

Since the model does not use detrended data, the analysis of frequency-specific correlations is an interesting option. Note that it amounts to ideal band-pass filtering of the model. population correlations and also using population frequency-specific correlations in the business cycle frequency range of 6 to 32 quarters, following King and Watson (1996).

Trimming the lowest and highest frequencies usually delivers a more plausible set of correlations of the model with estimates for the Czech data – see Fig. 7 for an example of correlation and frequency-specific correlation between CPI inflation and exchange rate growth. Note that the figure depicts population correlations with sample estimates without confidence bands.

By analyzing frequency trimmed moments we do not intend to say that certain frequencies, especially the low ones, are unimportant. On the contrary, a careful analysis of the parametrization with respect to trends is carried out. This is because the specification of the (stochastic) trending behavior of the model usually spills over all frequencies, not just the lowest ones. A textbook example is the different reaction of the current account to permanent and transient shocks with implications for business cycle frequencies. Andrle (2008c) demonstrates what portion of the filtered (by the Hodrick-Prescott, ideal band-pass or arbitrary linear filter) data covariance structure can be attributed to permanent and transitory shocks.

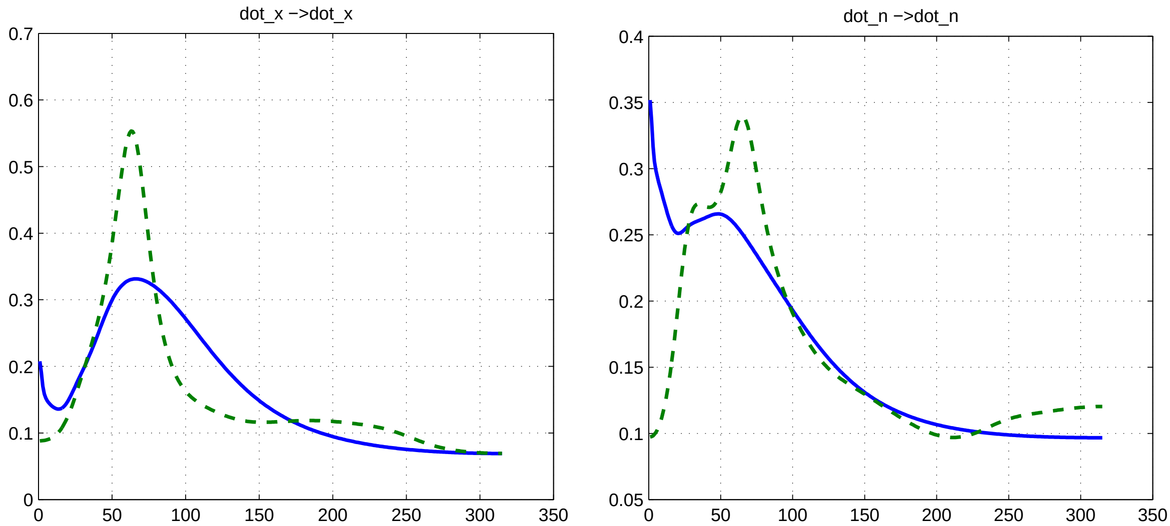
Some further frequency-domain investigations A discussion of stochastic trends and business cycle dynamics calls naturally for an explicit frequency-domain analysis of the model's population properties. After the first analysis of the spectral properties of the model we found that our first-pass calibration of the stochastic trends was at odds with several stylized facts.

King and Watson (1996) discuss a *typical spectral shape of growth rates* for key macroeconomic variables – GDP, prices, money aggregates, etc.[9] A "typical" growth rate of macroeconomic variables has a humped-shape spectral density with a peak at a cycle of 20–45 quarters and declines at high frequencies.

[9] This is reminiscent of Granger's typical spectral shape of economic variables. The problem with Granger's analysis is that it discusses non-stationary variables.

Proper specification of the trends in our model is crucial in order to understand the *role of trends in the forecast dynamics* and in *initial conditions identification.* It is crucial to keep sound business cycle dynamics and let stochastic trends rule the medium to long run.

Figure 8: Population and sample spectra of export and import growth



Note: solid line – model, dashed line – VAR point estimate

Since we model an open economy, Fig. 8 depicts population and sample spectra for quarterly growth rates of real exports and exports of goods and services as an illustration of the analysis.

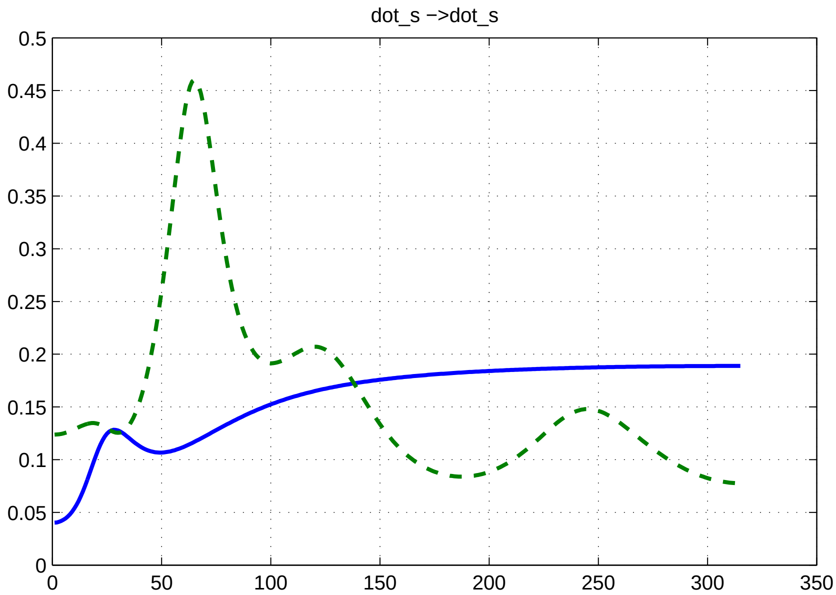
In this example parametrization the model would attach too much weight to low frequencies of import growth rates with respect to the data and export growth rates for our current specification. This mismatch manifests itself in coherence mismatch at very low frequencies and has consequences for trade balance dynamics. Another part of the problem is the dynamics of private consumption, which are affected by the stochastic trend in labor-augmented technology at low frequencies due to important wealth effects.

It might be interesting to note that there are some difficulties with getting the spectral shape of *exchange rate growth* in line with the data in the case of DNK-type models. An analysis based solely on the variance of the exchange rate growth may to some extent hide this problem. Fig. 9 presents our parametrization when pure uncovered interest rate parity (UIP) is used. One possibility that generates more plausible exchange rate properties is to introduce (in an ad-hoc manner) inertia terms into the UIP equation. Filtering exercises with this setup suggest this is a plausible specification.

5.2 Filtering and shock decomposition of the data

We use a linearized version of the model to identify structural shocks – unobserved technology trends and other variables, for instance real marginal costs in individual sectors. The *model-consistent filtering problem* is an important part of the calibration and the actual forecasting process. The model-consistent filtering serves to identify the *initial conditions* of the economy in relation to the calibrated equilibria during each forecasting exercise.

Figure 9: Population and sample spectrum of exchange rate growth



Note: solid line – model, dashed line – VAR point estimate

The model is close to being log-linear and the standard linear *Kalman filtering methodology* works for us well. We employ non-stationary observations in the filtering and use a standard diffuse Kalman filter (smoother).[10]

Although we employ the machinery of Kalman filtering, the model is not currently estimated using any likelihood-based methods. We spent a great amount of time obtaining a plausible model and filter setup, over and over again interpreting the story behind the filtered series starting from our priors. The approach is inherently a Bayesian one.

We use observations from 16 macroeconomic time series, including national account data for volumes and deflators, the consumer price index, net inflation[11], and regulated price index and rest of the world variables (foreign demand, inflation, interest rates) or the domestic nominal interest rate and exchange rate. *An important fact is that the measurement series are specified in levels*, thus the measured and model-percieved variables cannot not diverge.

Filter setup To set the variances of the structural shocks and measurement errors we used *structural shock decomposition* of the filtered data together with time-domain and frequency-domain analysis of the model properties. *The filtering problem itself is a part of the iterative model diagnostics.* See Fig. 12 on page 34 for an example of structural shock decomposition.

The *story-telling power* of the structural shock decomposition provided important guidance in setting the structural and filtering parameters and remains important step in the forecasting process. Using our priors, the academic literature, and information from the time and frequency domain on the model behavior we obtained a baseline calibration, where we considered the model setup to be satisfactory. The calibration-evaluation iterative process, including all parts

[10] In the paper we use the term filtering also for the Kalman smoother, since in principle it is just a two-sided linear filter.
[11] Recall from the discussion of regulated prices that "net inflation" is CPI inflation excluding regulated prices.

of the model diagnostics, is time intensive and is required after each major change of the model setup.

The analysis of the tightness of the measurement errors resulted in a fairly robust set of stylized facts. If we allow the measurement error to be large for real GDP components except private consumption, the information on relative prices delivers robust estimates of sector-specific trends. This is not surprising, as it is the nature of the balanced growth path.

5.3 Recursive filtering and forecasts

The forecasting properties are evaluated using the regular fully-fledged forecasts since Jan 2007. As such complex exercises are impossible to do for historical data, we resort to *recursive filtering and forecasting* exercises. In principle, we iterate on the regular forecast scheme, yet without imposing any expert judgment. Each time, a filter given the available data is run, the initial conditions are obtained, and the forecast is simulated. Then the sample is extended by one period and so on.

There are two important issues in evaluating the "fit" of the model to historical data – (i) the *information structure of the forecast* and (ii) the *unconditional nature* of the forecast.

Since we are simulating historical episodes, we know the actual realizations of the exogenous variables. The way we condition on these greatly affects the resulting forecast. We can either impose perfect foresight, use the expected trajectory of a relevant forecast *vintage*, or simply specify ARMA processes for these variables. This implies that a perfect knowledge of the actual evolution of, say, regulated prices or foreign demand need not improve the fit of the model to the data if in reality such a development was not expected in the starting period of the (historical) forecast. In addition, the endogenous monetary policy specified via the interest rate rule guarantees that unless unexpected shocks occur inflation will eventually reach its target. This might imply a different interest rate trajectory from the historical one in some periods. When one calculates RMSEs for DSGE models, it is thus necessary to understand the information structure of the exogenous variables and the unconditional nature of the forecast.[12]

The results indicate that the forecasting performance of the model is good enough for the model to be a useful analytical tool in the process of inflation forecast targeting. Its forecasting performance is comparable with the former QPM model. However, due to the different ways in which trends are treated, comparing the QPM and the g3 model is not straightforward.

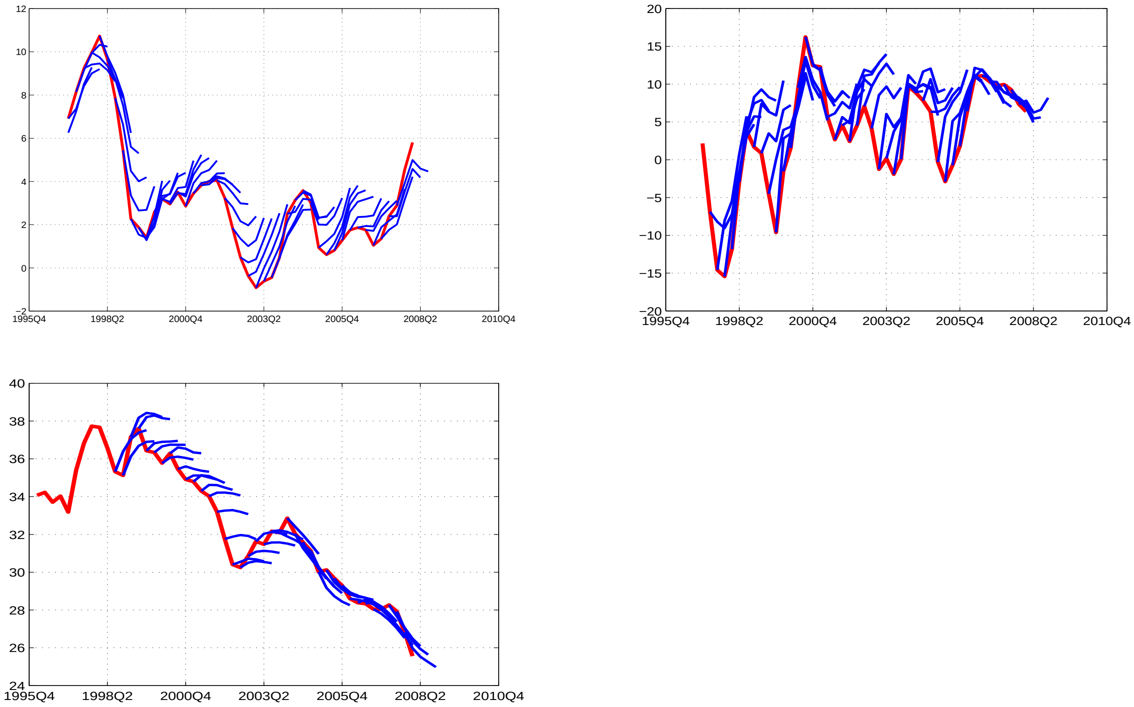
Fig. 10 presents an example of recursive filtering and forecasts of CPI inflation, gross real private investment growth, and the level of the nominal CZK/EUR exchange rate.[13] The mechanical structure and absence of conditioning makes the forecast different from the CNB's official forecasts.

The recursive exercise entails recursive identification of unobserved technologies and other structural shocks. Since the unobservables are based on smoothing, new observations reinterpret the history. This is a realistic feature of the test exercise. In fact, Fig. 10 is more an illustration of the procedure than a measure of the model's dynamic and forecasting properties.

[12] An intuitive example is higher-than-expected growth of regulated prices. Creating a forecast where all agents correctly anticipate a higher actual growth rate of regulated prices might result in a simulation with a very bad "fit" for interest rates, for instance. And this is right, since if the central bank knew about higher regulated prices in advance, it would correctly increase interest rates sooner to maneuver inflation toward its target. One cannot thus simply claim that making agents anticipate exogenous variables correctly must increase the fit of the model.

[13] The red line represents the actual historical data, while blue lines are forecasts. In the case of investment the fit is also worsened by the measurement errors in the filter that are not accounted for in the graph.

Figure 10: Recursive forecasts (T+4) – CPI (y/y), investment (y/y) and exchange rate (CZK/EUR)



6. Forecasting and policy analysis with the model

The structural model started to be used in January 2007, and official CNB forecasts have been produced using the new structural "g3" model since July 2008. The forecast results and the story of the forecasts are described in regular situation reports[14]. These results provide information on the stage of development of the model and give an alternative view on economic developments in the Czech Republic. During the period of shadow forecasting the forecasts were regular part of the situation reports and were discussed with Board members.

A cross-departmental forecasting team imposes a judgment based on expert views. The final forecast thus cannot be viewed as a mechanistic forecast.[15] The structure of the forecasting exercise is broadly similar to that of the QPM. This facilitates the use and communication of the new model and its results.

Our regular forecasting exercise consists of four main phases:

1. **Identification and interpretation of the initial conditions**
2. **Projection simulation conditioned on exogenous variables and judgment**
3. **Scenario analysis and forecast dynamics decomposition**
4. **Communication of the forecast**

During each of these steps the modeling team discusses the results with the forecasting team.

6.1 Identification and interpretation of initial conditions

The identification of the *initial position of the economy* with respect to its long-run equilibria is carried out using *filtering methods.*[16]

Since the model interprets observed levels and/or growth rates of macroeconomic data, the filtering process allows us to obtain *model-consistent estimates* of structural shock processes and thus of transitory and permanent technologies. Simply put, the filtering is used to identify the structural shocks that would deliver the observed data for the Czech economy. More than fifteen observed variables are used, most of them measured in levels.

The structural shocks identified convey the economic story behind the past development viewed through the lens of the model. This is useful not only for analyzing the past, but also for understanding current developments. The filtering exercise identifies the structural shocks that led to the current position of the economy in the business cycle. Analyzing the story behind the structural shocks identified and its reaction to new data and revisions is the key to understanding the *initial conditions of the economy.*

Use of measurement errors We decided that the model need not replicate every bit of "noise" in the data. Thus, we allow for *measurement errors.* Measurement errors in certain variables reflect our *expert priors* concerning their reliability, since we know that in some time periods there were revision problems, methodology changes, etc. Such use of measurement errors is different from the usual use of measurement errors to avoid stochastic singularity problems in structural models.

[14] The situation report is an internal analytical document containing an assessment of economic developments and the forecast of the Bank. It is used as a supportive document for monetary policy conduct. The external version is the Inflation Report.
[15] The forecasting team contains a modeling team.
[16] We employ a Kalman smoother. Since our measurement series may be non-stationary, we employ a version of the diffuse smoother.

Figure 11: Model-consistent filtering

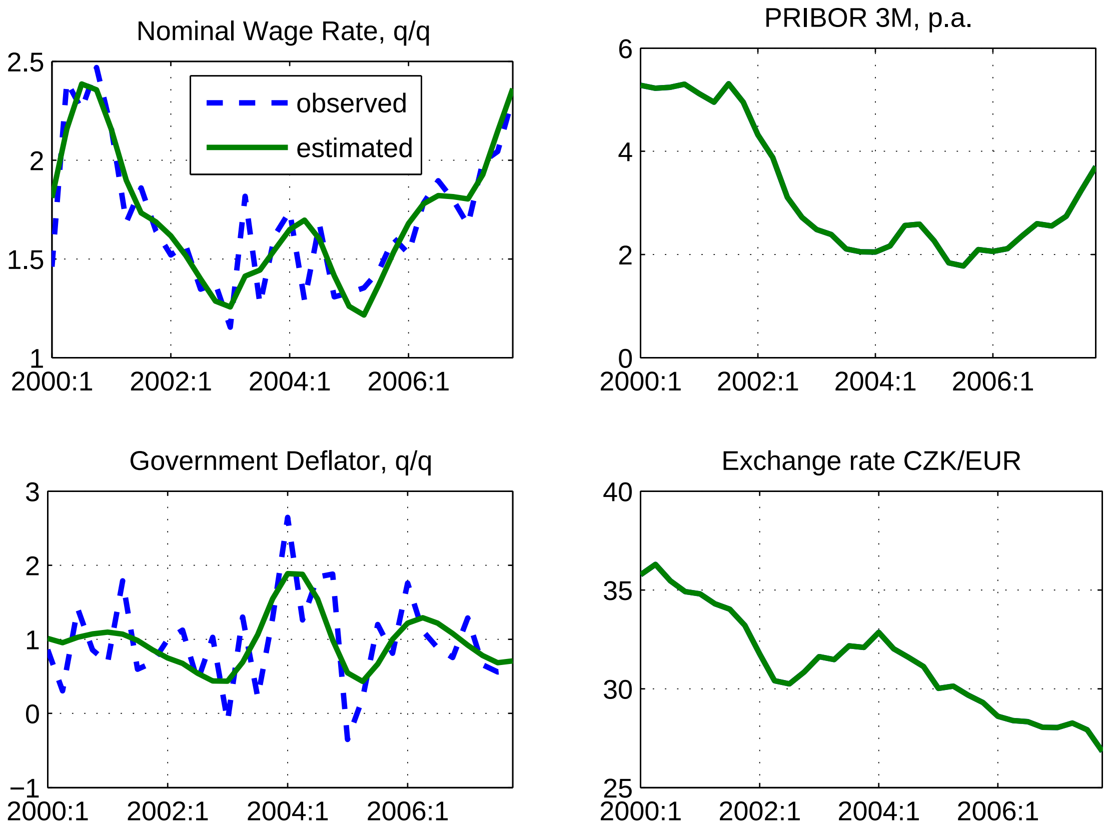


Fig. 11 demonstrates the idea of using measurement errors. One can see that policy rates and the exchange rate are assumed to be measured perfectly, whereas this is not the case for the government deflator and nominal wages, for instance. In these particular cases sectoral experts provided us with information on problematic features of the data, methodology revisions, etc. We treat measurement errors with great care.

We are also aware that in principle our approach may face difficulties distinguishing what is to be viewed as a *structural shock* included in the model and a *measurement error*.[17] We believe that our treatment of problematic or poor proxy variables using measurement errors is a viable solution reflecting expert knowledge of the data problems. We are, however, aware of the risks and trade-offs stemming from using measurement errors when interpreting the filtering results and assessing the latest economic developments.

If we use measurement errors, a significant portion of the information on a variable's dynamics can still be used by the model. That would not be the case if we excluded the observed variable from our measurements. However, forcing the model's structural shocks to replicate often a priori known problematic volatility and changes in all the variables entails spoiling the economics

[17] We would like to thank to Michel Juillard for a discussion of the issue at Bank of Finland Workshop on Implementation Issues of DSGE Models, Helsinki, May 2007.

of the model. Expert data transformations and modifications might perhaps serve as a viable alternative.

Although we consider the concept of *measurement errors* to be feasible for certain variables, extra care is necessary in communication and interpretation during the forecast. Filtered growth rates of error-measured variables need not exactly match the last figures in the raw data and care must be taken to account for this. The most important variables, however, are to be observed without errors. Recall that measurement errors are specified for levels of observed time series to prevent accummulation of stochastic trend error.

If the disparity between the filtered and raw data for error-measured variables is small we start the forecast using the filtered data. In the case of larger differences we investigate the factors behind the discrepancy in detail – what the deficiencies in the model or data are. Very strong prior information on some data problems is often signaled by sectoral experts.[18]

Shock decomposition of historical data It is not just the population moments of the model and filtered historical data that provide guidance on the filter setup. We make intensive use of *structural shock decomposition* of historical data.

The shock decomposition of observed data is obtained using the state-space structure of the model (4.45)–(4.47). The model variables $\{X_t, Y_t\}_t^T$ are then explained by evolution of structural economic shocks $\{\varepsilon_t\}_t^T$ and measurement errors $\{\xi_t, \eta_t\}_t^T$.

Firstly, this allows us to test the setup of both the model and filter parameters given our priors on the economics of the historical evolution. Secondly, if we believe the model is plausible it allows us to *interpret historical development*, to identify selected structural shocks, and to assess their impact on inflation.

Fig. 12 demonstrates the structural shock decomposition of real investment growth.[19] The prominent role of labor-augmenting technology (*eps_A*) and sector-specific technology (*a_J*) is clear. In certain periods, namely the year 2002, the influence of exchange rate shocks and habit formation shocks (*habits*) dominated investment growth.

We regularly investigate a set of variables to get an intuition for the model and filter setup and to explain the initial conditions of the economy at the start of the forecasting exercise. There is still an open issue of how to clearly and unambiguously communicate *monetary policy shocks* to members of the board and to the general public. One has to realize that monetary policy shocks do not imply any sort of error by members of the board, but reflect deviations of the actual data from the model's interest rate rule. As such, they make an interesting contribution to the discussion of both monetary policy making, conditioned on the stylized economic model, and the model setup itself.

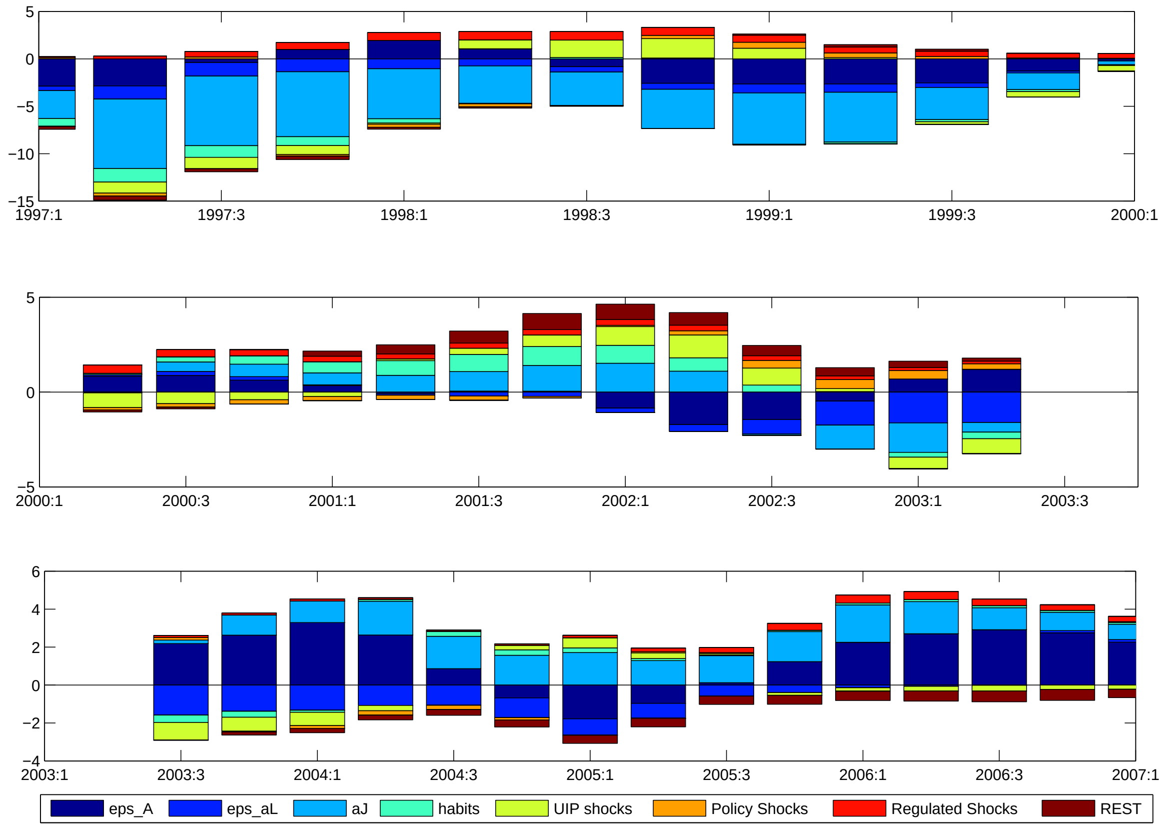
6.1.1 Interpreting news and revisions

When two-sided filtering using a structural model is used for identifying the initial state of the economy, new data and data revisions lead to revised estimates of structural shocks and unobserved variables.

[18] For instance, during the April 2007 forecast there was a last-quarter consumption growth discrepancy between the model-filtered growth and the NTF outlook and the situation was discussed in detail. Although the model is not perfect and one cannot generalize, new published data favored the model's real-time assessment of the economic situation. We believe that the potential of the model to "correctly" identify the unobserved state of the economy using its structure and measured variables is large, judging from recursive initial conditions identification exercises.

[19] We usually work with groups of shocks to get a clear message. Alternatively, we choose a number of the most important shocks to plot and let the others collapse to the "rest" category.

Figure 12: Structural shock decomposition of investment growth



Note: *eps_A* – labor-augmenting technology shock, *eps_aL* – labor force shock, *aJ* – investment-specific technology, *habits* – habit formation shock, *UIP shocks* – white-noise and debt-elastic UIP shocks, *Regulated Shocks* – shocks to regulated prices

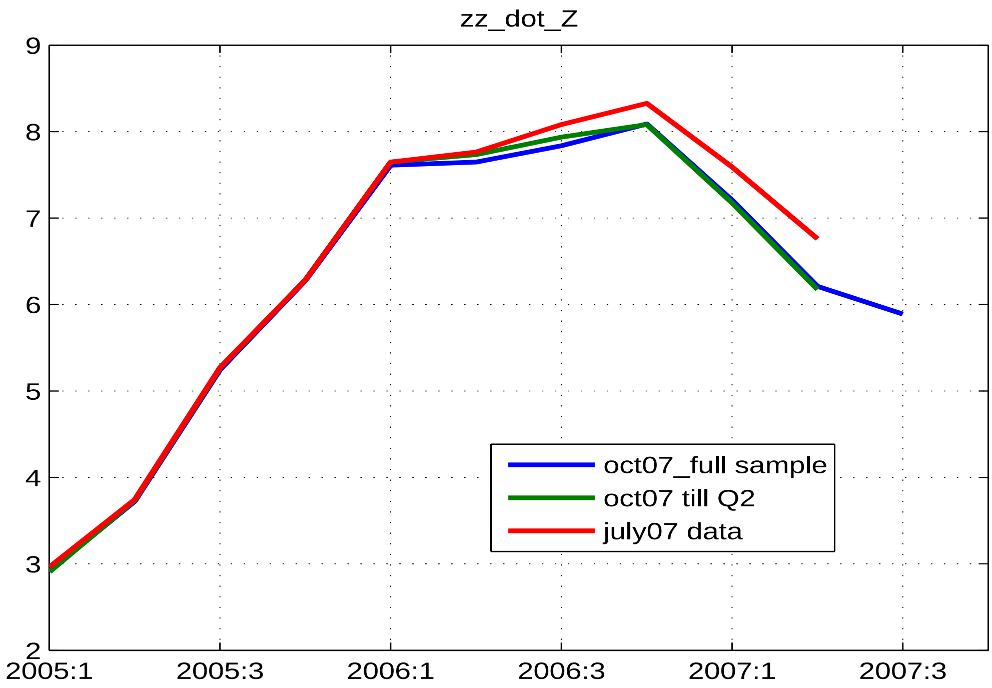
Understanding changes in the assessment of the current economic situation due to new data and changes in data is of utmost importance and a key knowledge for forecasting. We therefore put an emphasis on analyzing and understanding *news and revisions.*

There are basically three sources of possible revisions of the assessment of the economic situation: (i) *revisions of data and NTF nowcast updates*, (ii) *observing new period (quarter) information* and (iii) *changes in the model structure or parametrization.* These three phases are illustrated using the example of q-o-q annualized growth of aggregate implied productivity Z in Fig. 13.[20]

First, we analyze the revision of the past data and an update of the previous NTF outlook using officially released data (concerning GDP components mainly). If the nowcast for the quarter is far away from the officially released data the model interprets the economic situation differently. In the second step we analyze how the *new information* for the current quarter modifies the assessment of the economy. Note that the "new data" include both published data and the NTF outlook for some data due to data-release lags.[21] The role of changes to the model is the last step, stemming from the fact that the model is still being developed.

[20] The third stage – the difference due to a change in the model structure– is not depicted there.
[21] The NTF (near-term-forecasting) nowcast for GDP components can be supported by high-frequency observations either informally or using formal dynamic factor models.

Figure 13: Revision of initial conditions assessment, implied technology growth



To understand what observations contributed to a change in a particular unobserved filtered variable, we *calculate the contributions of observables to the change in the filtered variables,* for instance technologies or real marginal costs. In principle this allows us to see how individual signals from the economy are interpreted by the model. To give an example, when we observe massive growth in real economy aggregates without observing increases in inflation or other factors, the model can calculate the implied change in a particular technology that replicates the observed data.

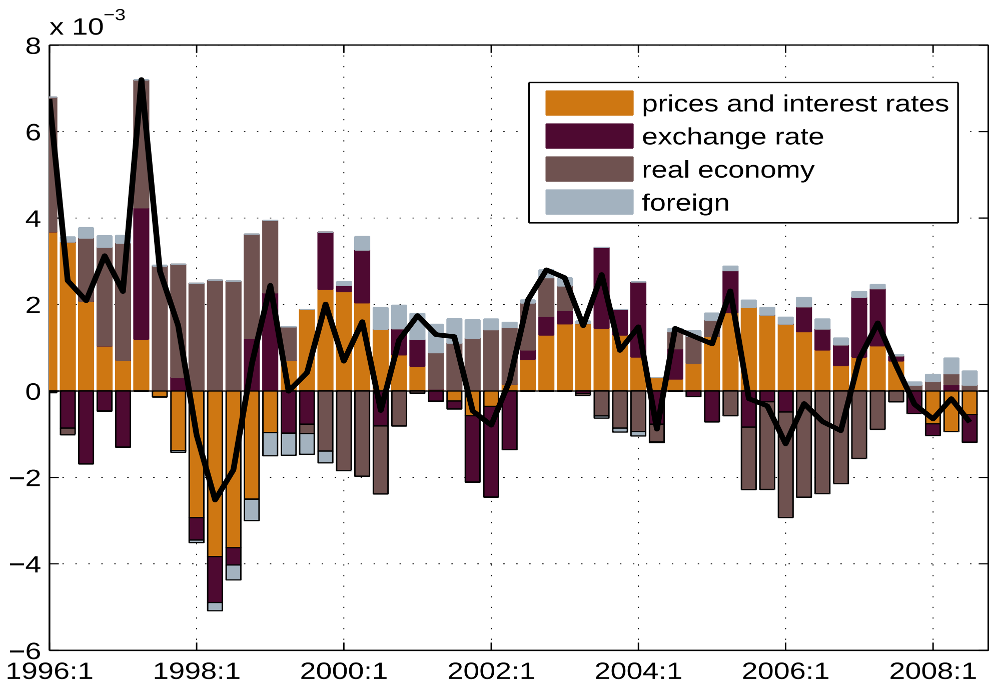
Note that in contrast to historical structural shock decomposition one can decompose unobservable shocks and variables into observables since the state-space structure of the model implies a multivariate linear filter

$$[X'_{t|T}, \varepsilon'_{t|T}] = \sum_{k=1}^{T} W_k Y_k, \tag{6.48}$$

where T is number of periods and W_k are weight matrices. The useful case of $T \rightarrow \infty$ can be also easily explored both in time and frequency domain, see e.g. Gómez (2006). Using this relationship, we can analyze what observables (or groups of observables) determine the identified values of shocks and unobserved variables given the model structure. For instance Fig. 14 presents decomposition of willigness to work innovations into four group of variables.

In the first step, we compare data revisions using only an identical range, and changes in filtered variables are mapped to changes in observables. An example of the decomposition step for aggregate implied technology growth is given in Fig. 15. In the second step, we analyze the

Figure 14: Shock decomposition into observables – work preference innovation



effect of how new period observation differences in filtered variables are mapped to the difference between the observed data and the model forecast as implied by the full model structure, conditioned on the appropriate information set.

In our view, the assessment of the latest economic developments (initial conditions) is inherently and always a *signal extraction problem,* Andrle (2008a), regardless of whether formal or informal methods are used. It is not enough just to acquire the data; the information in the data must be interpreted as well. Using a structural model allows us to consistently interpret the information available and carry out sensitivity analysis, and facilitates hypothesis testing.

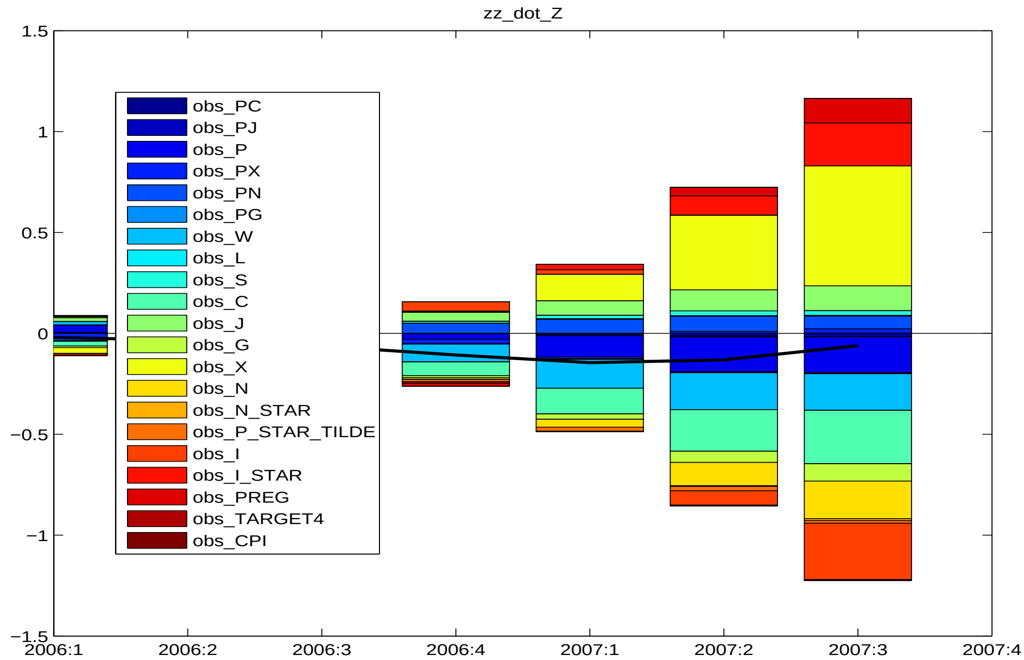
Understanding the reasons behind a change in the assessment of the economy is crucial. Decomposing the change into factors offers such an understanding. In addition, using formal or informal methods one can experiment and/or consistently weight pieces of information proportionately to the objective or subjective view of their signal-to-noise ratio.

Can we tell when the party is over? A proper understanding of data revisions and the effects of new information is of similar importance as the forecast simulation itself, since the initial conditions affect the forecast significantly.

Note, however, that even in the absence of data revisions and with perfect nowcasts, revisions of the filtered variables (real marginal costs, technologies, ...) are *almost inevitable.*[22] Economic shocks propagate through the economy in a complex way over many time periods and their detectability depends on the structure and size of the information available.

[22] Revision properties can be analyzed and linked to the structure of the model.

Figure 15: Decomposition of a filtered variable – the effect of data revisions



Note: abbreviations of observables: PC – consumption deflator, PJ – investment deflator, P – net-inflation, PX – export deflator, PN – import deflator, PG – government deflator, W – wages, L – employment, S – nominal exchange rate, C – consumption, J - investment, G – government spending, X – exports, N – imports, N_STAR – foreign demand, P_STAR_TILDE – foreign prices, I – domestic nominal interest rate, I_STAR – foreign nominal interest rate, PREG – regulated price index, TARGET4 – inflation target, CPI – CPI index

If we assume that all shock innovations are unexpected, they can be identified only using the information in the period they occur and in subsequent periods.[23] The higher is the number of cross-restrictions among the model variables, the better and *timelier* is the identification of structural shocks from the data. On the other hand, the more persistent is the model, the higher is the tendency to revision, other things held constant. Unless there are strong cross-restrictions in the short term, the last-period estimates of structural shock innovations are subject to revisions. A structural multivariate setup of the model offers such cross-restrictions.

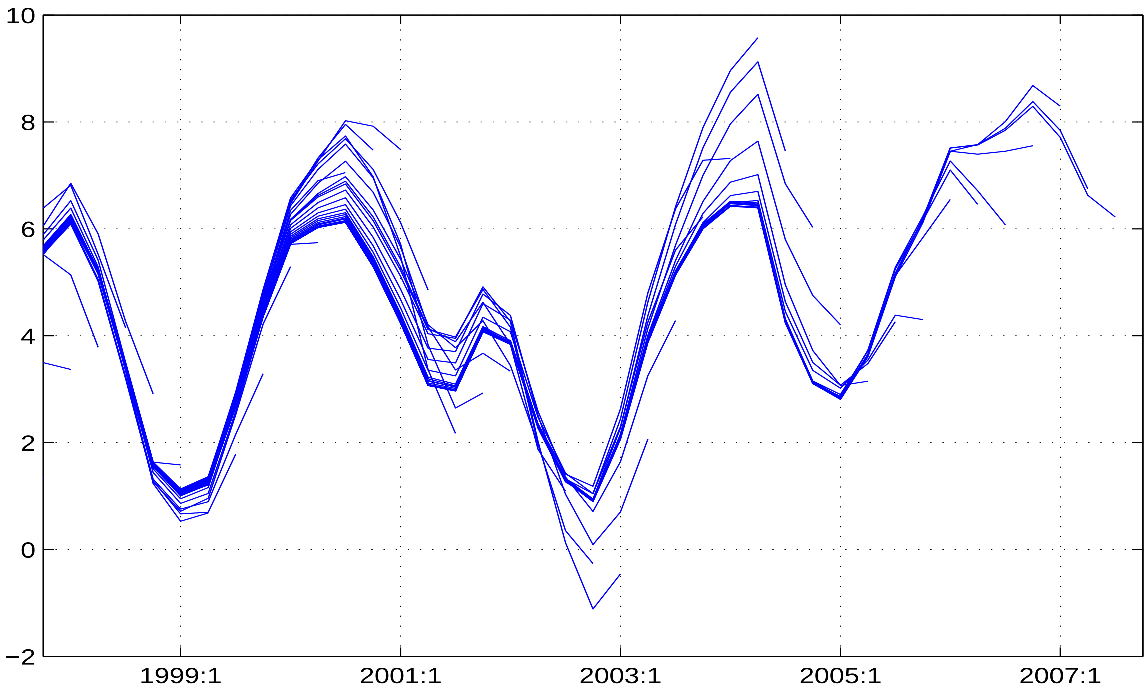
In Fig. 16 we illustrate the recursive identification of aggregate technology growth. Note that this figure is simplified, since no data revisions and nowcast updates are included. Only the effects of updating the information set for the new quarter is considered.

Inspecting the results in Fig. 16 we can make an (informal or formal) inference on the reliability of the filtering exercise and the magnitude of the revisions. Note that the tendency toward revision is different for different variables. For the particular example given, our view is that the filtering exercise can yield valuable information about the tendency of the real economy and the development of inflation pressures and threats.

[23] Note, however, that even unexpected structural shocks' filter weights are double-sided, although they can be expressed in terms of current and future prediction errors only. The law of motion of the transition process, however, is responsible for these prediction errors, based on past data. Information on the difference between actual and doubly-infinite filter weights can be easily obtained.

During the forecasting round we interpret and communicate changes in the assessment of the economic situation and the reasons for them. Communicating with sectoral experts is particularly helpful, since additional sources of evidence (surveys, data not included in the model, expert views, monthly data, . . .) are put together to sharpen our view of the current situation of the economy.

Figure 16: Recursive identification of aggregate technology



6.2 Producing the forecast with the model

Having identified the initial conditions of the economy, we proceed to forecast simulations. The forecast is based on the initial conditions of the economy and is further conditioned on the assumptions of the exogenous variables' trajectories.

In agreement with the CNB's existing QPM model the new structural model's forecasts are produced assuming *endogenous monetary policy responses* derived from the monetary policy rule of the model. As we have already stated above, monetary policy operates via setting a trajectory for the nominal interest rate in a regime of inflation targeting. In this respect we can label the forecast as an *unconditional forecast.*

The forecast, however, is *conditioned* on the trajectory of the exogenous variables. The most important variables we condition on are: (i) the *foreign demand, inflation and interest rate paths* as specified in the Consensus Forecast used by the CNB forecasting team, (ii) the *inflation target trajectory*, (iii) the *near-term outlook for regulated prices*, and (iv) the *government spending projection.*

However, the forecast is also conditioned on the assumed trajectories of all exogenous structural shocks in the model, namely *technology processes* and *risk premiums* – see the detailed discussion below.

Concerning all exogenous processes we could assume that there are no structural shock innovations over the forecast horizon. Then the stochastic processes for these shocks would follow their laws of motion, which are considered in the decision rules of all agents in the model. Where we need to impose a specific trajectory, i.e., we need to condition on the specific trajectory of exogenous variable(s), we have two options for each – *unanticipated* or *anticipated shocks.*

Anticipated vs. unanticipated shocks In January 2007 we started producing the forecast using either unanticipated shock conditioning or the fully anticipated trajectories of all structural shocks. Recently, we have consistently adapted our solution and analytical methods to allow for *mixing of some unanticipated and some fully anticipated shock trajectories* and expectation shocks into these trajectories.

Using both anticipated and unanticipated shocks together gives us an opportunity to allow for a perfectly anticipated trajectory of the foreign interest rate path, for example, while retaining the possibility of expectation shocks regarding technology processes and other variables.

Our view is that the combination is beneficial. Assuming perfectly anticipated trajectories of foreign variables is in line with the subjectively viewed (expected) trajectories of model agents and the monetary authority. It is also consistent with the overall assumption of the CNB's forecast, which is conditioned on *particular expected* trajectories of selected economic variables.

Note that even in the case of a specific fully anticipated trajectory of a particular exogenous variable *we can still hit the economy with expectational shocks.* This practice is in line with the vintage updates of the CNB's forecasting, where the forecast is conditioned on in a certain trajectory and next-period expectation shocks possibly occur in all periods of the trajectory's range. An expectation shock thus can be regarded as a change in the expected profile of a variable.

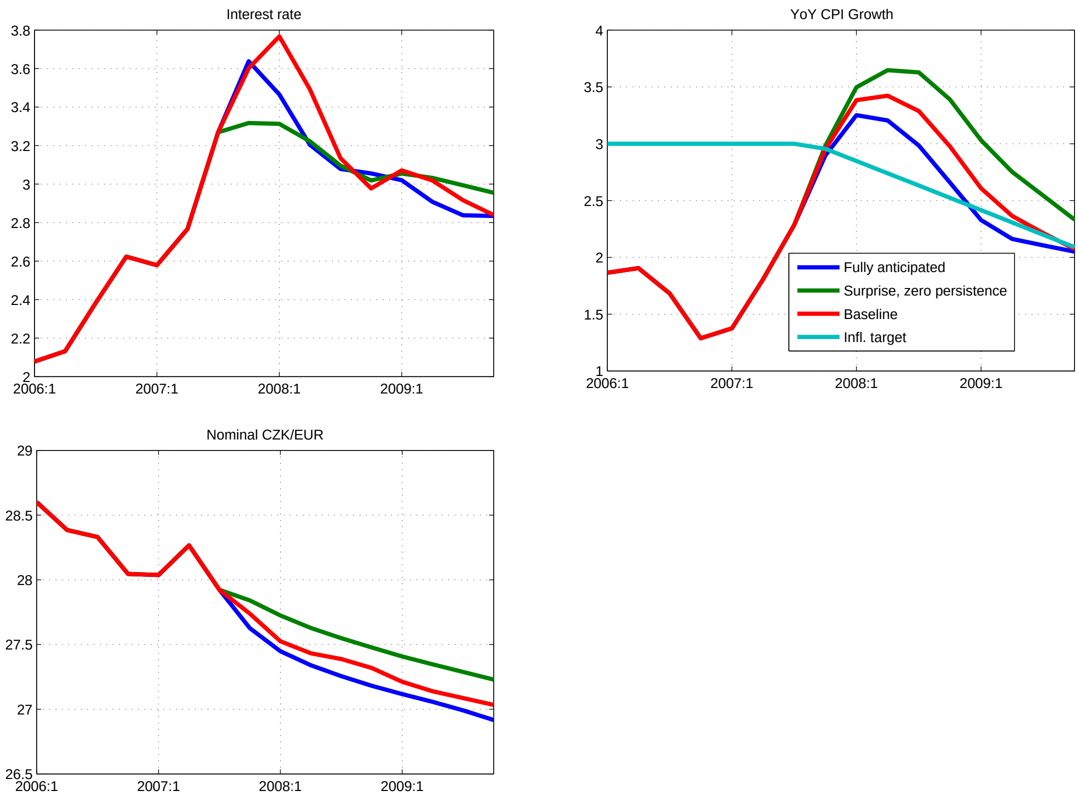
We consider scenario analysis with alternative assumptions not only about the trajectories of exogenous variables, but also about whether these are anticipated or unanticipated, to be a very important exercise. To give an example, simulations with anticipated/unanticipated alternative technology shocks are of some policy interest. We can also simulate the anticipated evolution of a specific transitory or permanent technology that does not materialize (boom-bust scenario).

Fig. 17 briefly presents a scenario analysis for the treatment of regulated prices. In the baseline case the regulated price trajectory is simulated using surprise innovations where the process driving the expectations of regulated prices is moderately persistent. As an alternative we consider the same simulation with zero persistence in the process and a perfectly anticipated trajectory of regulated prices.

Note that in all scenarios the same trajectory of regulated prices eventually materializes. Yet the expectational assumptions are very important. In the zero persistence case the surprises are different from the persistent case, where there are both positive and negative expectational shocks and shocks tends to propagate into the expectations of all agents due to rather high persistence.[24]

[24] A detailed analysis was published in the CNB's October 2007 Situation Report.

Figure 17: Regulated prices – anticipated vs. unanticipated



6.3 Conditioning, exogenization, and imposing judgment

All forecasts produced by the model are *judgmental forecasts.* Judgment is propagated through the calibration of the model, in the filtering setup, and when *specifying the trajectories of structural shocks.* We impose judgments via (i) *filter tunes* and (ii) *forecast tunes*.

Filter tunes To identify structural shocks correctly it is sometimes feasible to provide a model-consistent filter with additional information not captured by the structure of the model. An example would be an idiosyncratic wage increase due to tax optimization or a change in methodology. Given constant variance of wage cost shocks a part of the idiosyncratic wage increase can be attributed to technology development, which model users may judge undesirable and impose a higher cost-push shock to avoid it.

In principle, filter tunes allow model users to set any variable to any value in any period in such a way that the whole model filtration reflects it. The method used allows us to impose linear equality constraints on unobserved variables using state-space augmentation techniques.

$$X_t = AX_{t-1} + R\varepsilon_t \tag{6.49}$$

$$\begin{bmatrix} Y_t \\ Y_t^J \end{bmatrix} = \begin{bmatrix} BX_t \\ \Gamma X_t \end{bmatrix} + \begin{bmatrix} S \\ 0 \end{bmatrix} \xi_t, \tag{6.50}$$

where Y_t^J is a vector of filter tunes. A feasible and important requirement for efficient filter tunes is that the filter implementation can handle missing data. To impose a particular value of an unobserved variable in a particular period, the user just creates an additional measured time series (part of Y^J) and links it to the transition variable. The additional measured series has missing values with the exception of particular periods where judgments are imposed.

The *ability to process missing observations* is one of the convenient features of the Kalman filter, see e.g. Harvey (1989). Apart from data irregularities it is used to run *unobservables counterfactual scenarios*, delivering the model's estimate of variable's value conditioned on other observables.

Forecast tunes However, we may also impose judgment in terms of exogenizing a particular endogenous model variable. Note that literally all technology processes are also endogenous model variables, since only innovations are exogenous. Often one may be interested in fixing the trajectory of a variable that is not expressed as a simple AR process, for instance.

To impose judgment on the development of a particular variable or variables we endogenize structural shock innovations and the trajectory of these innovations meeting the required constraints is found. *The crucial decision is, however, by which structural shock or set of shocks the required trajectory of endogenous variables is to be delivered and whether these shocks should be treated as anticipated or unanticipated.*

To *exogenize* a specific variable in particular periods one has to decide which structural shock innovation to *endogenize* and in which periods. These periods need not be overlapping. However, if we require the current evolution of the specific variable to be explained by future innovations, we need to assume that these innovations are anticipated by all agents in the model. In the current forecasting setup we allow for a mix of anticipated and unanticipated shocks when fixing variables and imposing judgment.

We can exogenize a variable either by a specific structural innovation or by a set of innovations. In the case of a predetermined system the solution in terms of innovations needed is not unique. Following e.g. Sims (1982) or Waggoner and Zha (1998) we can choose the set of shocks that is the *most likely,* which is basically a least-squares problem.

Concerning the treatment of both anticipated and unanticipated shock innovations, we usually focus on *hard conditions* or tunes in the terminology of Leeper and Zha (2003), i.e., we condition on a fixed trajectory, not on an interval. Currently the model's implied forecasting densities are not used in communication with policy makers. The feasibility of a judgment can be judged by the size of the shock with respect to its model properties, i.e., whether the shock is modest.

6.4 Modest policy interventions vs. anticipated shocks

Although the CNB's forecasts are *unconditional* with respect to a pre-specified interest rate path, a conditional scenario or forecast is a possible alternative. Many central banks have also used or are still using the assumption of *no policy change.* However in a forward-looking structural model such a strategy needs to be well understood and communicated.

As far as we know, the constant interest rate path is often simulated by exogenizing the nominal interest rate variable and endogenizing structural shock innovations, usually a monetary policy shock, assuming *these innovations are unanticipated.* Leeper and Zha (2003), however, warn that simulations conditioned in this way may not be *modest policy interventions,* since under certain conditions agents could revise their beliefs about the policy (rule). Rational expectations are not consistent with systematic fooling of the model agents for too many periods.

Fixing interest rate path for certain periods using an *anticipated policy shock* has both a different interpretation and different effects on the economy than using unanticipated shocks repeatedly. In this case the policy maker announces that for several periods he or she will deviate from the rule and keep interest rates constant. Agents thus know that whatever happens is going to be buffered by a monetary policy shock, for instance. Constant interest rate paths with credible announcement and anticipated shocks are thus an interesting simulation option. Keeping the nominal interest rate elevated for too many periods leads –in line with Fischer equation– to increase in the expected and then actual inflation for instance. The economy may settle in a new equilibrium with higher inflation and unchanged real rate of interest. Since this issue is not the core topic of the paper, we do not discuss further details.

The reason why we discuss the issue of conditioning on an interest rate path is that some economists would like to "switch-off" the monetary policy rule (equation). What needs to be realized is that it is impossible to "switch-off the policy rule". One can, however, condition on a particular interest rate path and there are many ways of achieving this goal, leading to different results. One is then obliged to communicate the strategy used and its potential implications.

The most inappropriate way of trying to "switch-off" the policy rule is to manipulate the model's coefficient,[25] since such a strategy is inconsistent with the structure and philosophy of the model-consistent expectations equilibria.

6.5 Scenario analysis and forecast dynamics decomposition

In order to capture the uncertainty of the forecast produced we carry out a scenario analysis with respect to the main variables of the model and the major risks we see at the forecasting horizon. The scenario analysis serves also for gaining more intuition and better understanding the forecast dynamics.

The scenarios may differ not only in alternative paths of exogenous variables, but also in whether and what economic categories are anticipated or unanticipated and what the risks stemming from expectational shocks are.

Although the alternative scenarios are useful for assessing risks and increasing the general understanding of the forecast, they are silent on what factors contribute to a particular trajectory. To uncover these contributions we implemented tools to decompose the dynamics of the model into individual factors. These tools can treat both linear and non-linear models and are adapted to treat mixing of anticipated and unanticipated shocks – see Andrle (2008b).[26]

From the start of the forecasting exercises we use these decomposition tools to (i) *decompose the alternative scenarios into factors,* (ii) *decompose the dynamics of the simulation with respect to a steady state* and (iii) *analyze sources of difference between two successive forecasts.*

We decompose the simulation's dynamics into all factors affecting the dynamics – (i) the initial conditions and (ii) the trajectory of exogenous variables, being either anticipated or anticipated. For these decompositions to be useful outside the modeling team, its principles need to be clearly communicated.

[25] Unless all agents are informed about this possibility.

[26] The set of tools enables the modeling team to decompose the dynamics of the forecast with respect to steady state, alternative simulation or changes in the observed data via filter decomposition. The tools handle both linear and nonlinear models and feature a very flexible user interface for reporting and aggregating factors of difference into separate groups according to range, type of variable and/or name.

First, the initial conditions are the result of a model-consistent filtering exercise. Thus they are not independent and reflect past structural shocks. Second, the ceteris-paribus nature of the dynamics decomposition needs to be borne in mind.

The decompositions of the components as in Fig. 18 are transparent and order-independent. *The analysis is useful for communicating the reasons for a particular inflation or interest rate forecast path, both for the baseline scenario with respect to the equilibrium and for the current forecast with respect to the last-period forecast.*

Figure 18: Successive forecast difference decomposition (policy rate)

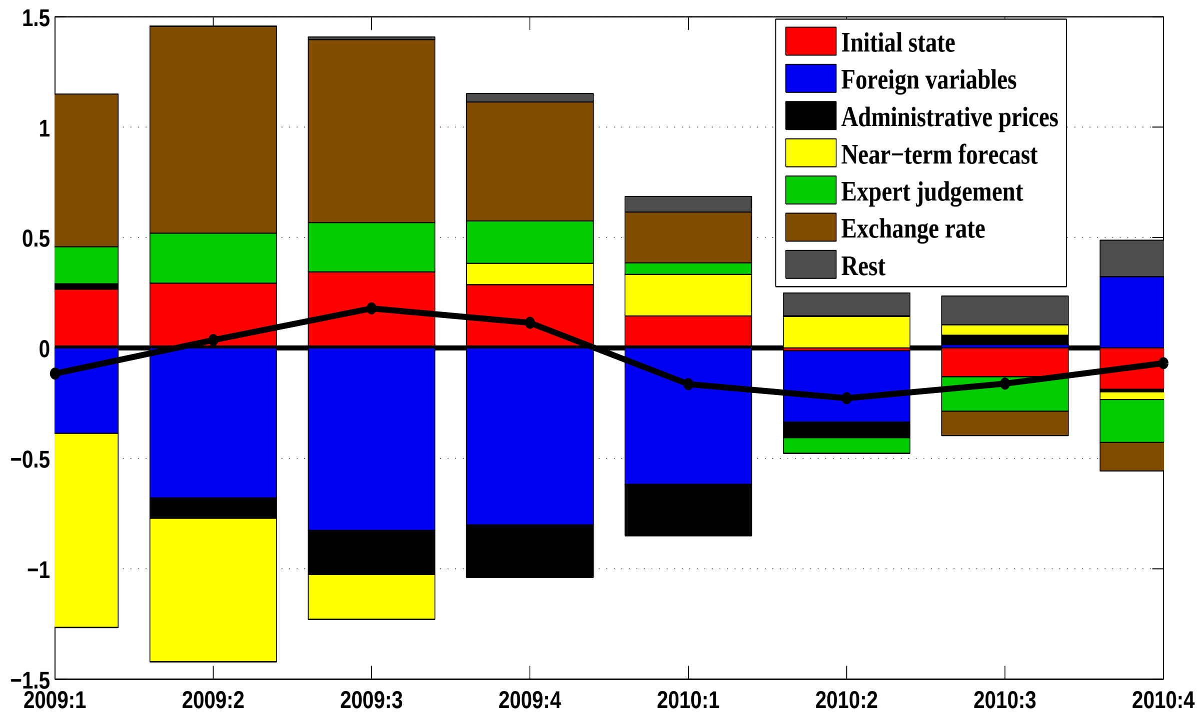


Fig. 18 illustrates the decomposition of changes between two forecasts. Taking care over the information set structure we can decompose these differences to highlight the main sources of the difference between the two trajectories. In the illustration of Fig. 18 we would identify disinflationary pressures stemming from the new outlook for foreign variables, from the near-term forecast, and from the administrative price forecast. The near-term forecast represents a sectoral expert assumption about price developments in the very first quarter of the forecast. In the presented example the disinflationary pressures are offset by inflation pressures from the exchange rate assumption (the very first quarter reflects already available observed data and expert views), from the initial state, and from expert judgments.

We comment in detail on these decompositions and the effects of individual factors on the *interest rate path* in a special box of the situation report. The presented forecast is thus *very transparent* in terms of assumptions, results, and details of the analysis. Importantly, the story behind the forecast can be always articulated without explicit reference to the particular model used, which allows us to focus on the economic intuition behind the forecast, supported by a consistent and flexible analytical tool.

Similarly to the *interpretation of the initial conditions* and the position of the economy in the business cycle, the value of model-supported forecasting lies in being able to analyze differences in successive forecasts. Hence, despite the potential insufficiencies in the model's forecasting performance we can keep track of the story implied by the model and the way in which the model interprets *new information.*

Inflation-target fulfillment The method of consistent forecast updating is a continuation of the forecasting practice with the QPM model, where sophisticated methods of inflation-target fulfillment assessment were developed and used at the CNB.

We consider the ex-post forecast evaluation step to be extremely important for transparent and accountable monetary policy conduct and it is a priority. Compared to the inflation-target fulfillment evaluation with the former QPM model the structural form of the g3 model delivers a richer and more consistent story, including the identification of structural shocks.

7. Communication issues

Communication is an important aspect of model-supported policy making. Communicating the principles and results to members of the board, CNB staff, and the general public in a clear and transparent way is our goal. In order to achieve this, some basic terms and concepts must be agreed upon to avoid misunderstandings and confusion.[27]

It should be clear what questions can and cannot be answered using the model, what economic concepts are used, and how to understand them. The new "g3" model introduces some new concepts while abstracting from others. Clearly, the model has been developed in order to obtain a structured and flexible analytical tool, not to change the way monetary policy is conducted.

We think that the issues of unconditional forecasting, the definition of equilibria, forecast integration, and technology processes are of key importance.

Unconditional forecast The communication of the model and model-supported forecasting was greatly facilitated by the widely accepted use of the QPM model. The notion of model-consistent expectations and especially the concept of *endogenous forward-looking monetary policy rule* have been in use at the CNB for several years. That is an important achievement.

Both the members of the board and the general public are used to forecasts unconditioned on a specific interest rate path. The *interest rate path consistent with the inflation forecast* was communicated verbally. Since 2008 the interest rate path has been published and accompanied by a fan chart to account for forecast uncertainty.

In this respect the g3 model is fully compatible with the existing practice and no changes in communication in this area are needed. However, there are areas where communication will be different, in particular the treatment of the *output gap* concept and the *definition of equilibria.*

The notion of the current equilibrium or *natural rate or potential level* of a variable needs to be defined and measured, if needed. There are two concepts that could be used. First, the potential level might be viewed as the output of the steady-state, or balanced growth path. The second, economically sounder, concept is to define a natural rate or level as the one that would occur in a fully flexible environment without any nominal rigidities (neo-Wicksellian flex-price equilibrium).

[27] The communication of the model to public is also supported by lectures on the basics of the model for economic analysts. The way how CNB forecast and some key concepts of the model-supported analysis (real marginal costs, nominal marginal costs growth decompositions,...) are communicated to public may be viewed in presentation materials from regular 'Meeting with Analysts' at the CNB website.

The flex-price equilibrium is time-varying and is basically a result of real business cycle dynamics. Such dynamics could be more volatile than the actual dynamics of the economy, which might be intuitively unappealing to many practitioners and attractive to others.

If the flexible-price Neo-Wicksellian concept of natural levels of economic variables is found to be appealing, since it arises naturally in the framework of DSGE models, the operationalization difficulties of the concept might draw into question its practical usefulness for monetary policy. In general, policy-neutral interest rates and the natural level of output are highly model-dependent categories – see, for example, Amato (2005) for a non-technical discussion. In addition, real-time revision issues linked to the initial conditions relate to these natural levels.

However, the structural nature and behavioral underpinning of the g3 model represents a contribution toward a more consistent and clear definition and treatment of "natural levels". Their use for purposes other than analysis or research is left as an open issue.

Forecast integration By forecast integration we mean the integration of model-supported analysis with the expert judgment of the near-term forecasting (NTF) unit and the rest of the staff. Our view and available experience suggest that the detailed structural nature of the model and its focus on actual observed important economic variables, including interest rates, foreign demand, GDP structure, deflators, and other prices, are very similar to the NTF understanding of the economy. The integrated forecast represents a fixed point of model-oriented and judgemental forecast.

In particular, the explanatory factors behind many categories are the same, yet there is one important difference – the "g3" model offers simultaneity of analysis as opposed to partial equilibrium schemes. For instance, real export dynamics can be discussed in terms of foreign demand, real trade exchange rates or supply-side developments, while consistently taking account of interactions of these factors with other categories such as consumption, investments or imports to name but a few.

The NTF and model-supported results can thus be discussed in a common language and the model can serve as a framework for testing hypotheses and views.

Role of technology and other structural shocks In the model there is a prominent role for technology shocks as a major source of economic fluctuations. These are unobserved and thus estimated using the model-consistent filtering exercise. To simplify, they can be viewed as a *total factor productivity* development affecting both the economic cycle and long-run growth.

The notion of technology shocks is rather abstract and thus many real-world events and shocks may be represented by these shocks – supply-side effects of FDI, innovation activities and R&D or increases in the skilled-labor share to name but a few. When the evolution of technology growth is communicated it is important to view it in this reduced-form way and focus on the reasons behind its revision and/or assumed evolution at the forecast horizon.

In the g3 structural model the distinction between *supply shocks* and *demand shocks* is not clear-cut, which is intuitive. Individual structural shocks affect both the supply side and the demand side of the economy and their transitory or permanent and anticipated or unanticipated nature matters significantly.[28]

[28] The effect of a small permanent and anticipated technology shock may have significant immediate effects on spending and the demand side of the economy, for instance. Note that this expectation channel is an important source of demand shocks. In principle, an expectations error with respect to the development of technology growth may be a source of demand shocks in the past and at the forecasting horizon, since we may and we do introduce expectations shocks. See e.g. Lorenzoni (2006) for a theory of expectations-error demand shocks.

8. Conclusion

The purpose of the paper is to serve as a guide to the implementation of the new "g3" structural model of the Czech National Bank within the regular forecasting process. We have introduced the main characteristics of the model and focused mainly on *forecasting and policy analysis* with the model. The purpose of the paper was not to describe all the details of the structure, complete parametrization and behavior of the model, but rather to indicate the most interesting problems and suggest solutions in the case of an emerging economy.

Our experience with practical forecasting and policy analysis using the DGE model suggests that such models are very useful tools for monetary policy analysis and decision-making support. Most importantly, the identification of structural shocks over history and model-consistent identification of the business cycle position have improved the story-telling capacity and structural consistency of the forecasting process. However, a necessary requirement for regular forecasting is a properly built forecasting and policy analysis system (FPAS) enabling one to impose expert judgment and providing flexible reporting. The development of the model will continue since, obviously, not everything is perfect and there always is room for improvement.

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