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EDITORIAL

Appropriate, state-of-the-art forecasting techniques are crucial for guiding the monetary policy decisions of central banks. At the same time, knowledge of the initial conditions in the economy is a prerequisite for good forecasts. Such knowledge is incorporated as expert judgement on top of the model forecast. It is also important to understand which factors contribute to differences between two (old and new) forecasts. This edition of the Research Bulletin presents four articles that describe recently developed forecasting techniques, the role of expert judgement in the forecasting process, and a new structural model forecast evaluation technique used at the Czech National Bank.

The first article examines the forecasting performance of mixed-frequency data models and compares it to the forecasts regularly published by the Czech National Bank, which are based on single-frequency data and adjusted by expert judgement. The results show that models that employ data of different frequencies may be used as a complementary tool to the currently used forecasting techniques.

The second article focuses on the potential enhancement of density forecasts, which are used by central banks in the form of fan charts, by accounting for the effect of non-linearity between credit conditions and economic activity. The article shows that non-linear models deliver a more realistic assessment of the macroeconomic outlook than linear models, particularly during "stress" events such as the recent global financial crisis and when assessing the probability of hitting the zero lower bound on the nominal interest rate.

The third article outlines the forecasting process used at the Czech National Bank, focusing on the incorporation of expert judgement into forecasts. Using case studies, the article demonstrates that expert judgement is necessary for supplementing the core forecasting model outcomes.

The fourth article describes a newly developed framework used at the Czech National Bank to evaluate differences between two forecasts. The article shows that the new forecast evaluation methodology may improve the regularly published forecasts by identifying sources of forecast errors.

Kamil Galuščák

IN THIS ISSUE

Forecasting Czech GDP Using Mixed-Frequency Data Models

Central banks build their monetary-policy decisions on forecasts of macroeconomic variables, with GDP being among the most important ones. To exploit all the available and timely information, GDP forecasting models that directly employ data of different frequencies have been developed recently. In this article, we discuss the forecasting performance of such models and compare them with official CNB forecasts of GDP.

Michal Franta, David Havrlant and Marek Rusnák (on p. 2)

The Effect of Non-linearity Between Credit Conditions and Economic Activity on Density Forecasts

The recent economic and financial crisis suggested that non-linear behaviour of economic variables can play a significant role. A prominent example of this is the relationship between credit markets and real economy. This article examines the effect of such non-linearity on the forecasting of probability densities of future values of macroeconomic variables. It turns out that during stress events, accounting for non-linearity leads to more accurate probabilistic assessment of the economic outlook.

Michal Franta (on p. 6)

Incorporating Judgments and Dealing with Data Uncertainty in Forecasting at the Czech National Bank

This article focuses on the forecasting process at the Czech National Bank, with an emphasis on incorporating expert judgement. The article contains five case studies, which reflect policy issues addressed during forecasting rounds since 2008. The case studies demonstrate that careful incorporation of expert information is useful for generating economically intuitive forecasts even during very turbulent times, and we show that such judgements may have important monetary policy implications.

Jan Brůha, Tibor Hlédik, Tomáš Holub, Jiří Polanský and Jaromír Tonner (on p. 9)

Evaluating a Structural Model Forecast: Decomposition Approach

We developed an analysis framework designed to examine the differences between two forecasts generated by a linear structural model. The new framework allows us to decompose differences in forecasts into the contributions of individual changes in assumptions even when some assumptions are applied in anticipated mode. A replication of the Inflation Forecast Evaluation exercise contained in Inflation Report III/2013 is used to illustrate the full capabilities of the newly developed decomposition framework.

František Brázdik, Zuzana Humplová and František Kopřiva (on p. 12)

Forecasting Czech GDP Using Mixed-Frequency Data Models[1]

Michal Franta[a], David Havrlant[b] and Marek Rusnák[a]

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Forecasting of macroeconomic variables is one of the key tasks of central banks, as monetary policy decision-making draws heavily on expected future developments in the economy. The role of forecasting is especially important for inflation-targeting central banks, which affect the economy in such a way as to guarantee that the inflation forecast is close to the inflation target at a given monetary policy horizon. The accuracy of the inflation outlook depends on accurate estimation of the current and future values of other macroeconomic indicators. In this respect, GDP – an indicator of the performance of the economy – is one of the most important variables. An outlook of low GDP growth is consistent with low inflationary pressures. Similarly, an overheating economy is reflected in an upsurge in inflation.

A lot of modelling approaches have been developed to forecast GDP. They all possess the same feature – they are estimated on data of the same frequency. So, GDP data are available quarterly and if one uses, for instance, the interest rate to predict GDP growth, the data on the interest rate are aggregated into quarterly averages even though the value of the interest rate is available at higher (e.g. daily) frequency. Regarding the forecasting process there are, however, costs of ignoring the availability of higher frequency data and costs of aggregating data into data of lower frequency. First, we lose information through temporal aggregation. For example, if monthly data suggest a rise in a variable within the current quarter, the simple average is a less accurate piece of information for the next quarter forecast in comparison to taking into account the profile of the variable and considering the last (highest) observation from the current quarter as an appropriate predictor. Second, by sticking to low frequency data we lose the opportunity of providing real-time forecast updates at a higher frequency (e.g. every month when forecasting a quarterly indicator).

Recently, various models have been developed that are able to deal with data of various frequencies directly within one particular model. So, aggregation or interpolation prior to the estimation of the model and forecasting is not necessary. These models include mixed-frequency vector autoregressions (VAR) introduced by Mariano and Murasawa (2003), mixed-data

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[1] This article is based on Franta et al. (2014).

sampling models first applied by Ghysels et al. (2004) and the dynamic factor model as formulated by Banbura and Modugno (2014). In Franta et al. (2014), we employ these models to produce forecasts of Czech GDP. The models deal with monthly and quarterly data. So, for example, monthly data on industrial production, which provide relevant information for the GDP growth forecast, are taken into account. Moreover, the monthly frequency of the industrial production data allows for updates of GDP forecasts every month.

To examine the relevance of mixed-frequency data models for policy purposes, their forecasting ability is assessed and compared with the forecasts regularly published by the Czech National Bank (CNB), which are based on single-frequency data models and adjusted by expert judgement. The nature of the models used allows us to include financial indicators such as interest rates, credit growth and stock market growth. In order to exploit timely information we also add survey indicators about industry and consumer confidence. Finally, to capture the fact that the Czech economy is a small open economy, we also make use of several foreign indicators covering macroeconomic, survey and financial variables. Using this dataset, we evaluate the forecasting performance of the mixed-frequency data models over the 2005–2012 period.

The forecasting performance is discussed for nowcasting and forecasting separately. Nowcasts are forecasts for a given quarter which are conducted during the previous quarter, during the given quarter and in the first month of the next quarter. Nowcasts of GDP are used as inputs into the core CNB forecasting model, so models that are able to provide precise nowcasts are of great relevance. Forecasts are considered for up to six quarters ahead, which represents the end of the monetary policy horizon. The measure of forecasting accuracy used is the root mean squared error (RMSE) at a specific nowcasting/forecasting horizon.

The results suggest that for both nowcasting and forecasting all of the mixed-frequency data models considered are able to beat a naïve benchmark (a random walk – RW – forecast). For nowcasts, a striking increase in the precision of the nowcasts in the third month of the nowcasted quarter is found (see Figure 1). The finding is related to the release of GDP data for the previous quarter, which provides crucial information for the GDP nowcast. Overall, for nowcasting horizons, only the dynamic factor model (DFM) is able to compete with the CNB nowcasts.

Figure 1. Root mean square errors at different nowcast origins

RMSE evaluated using first releases of GDP
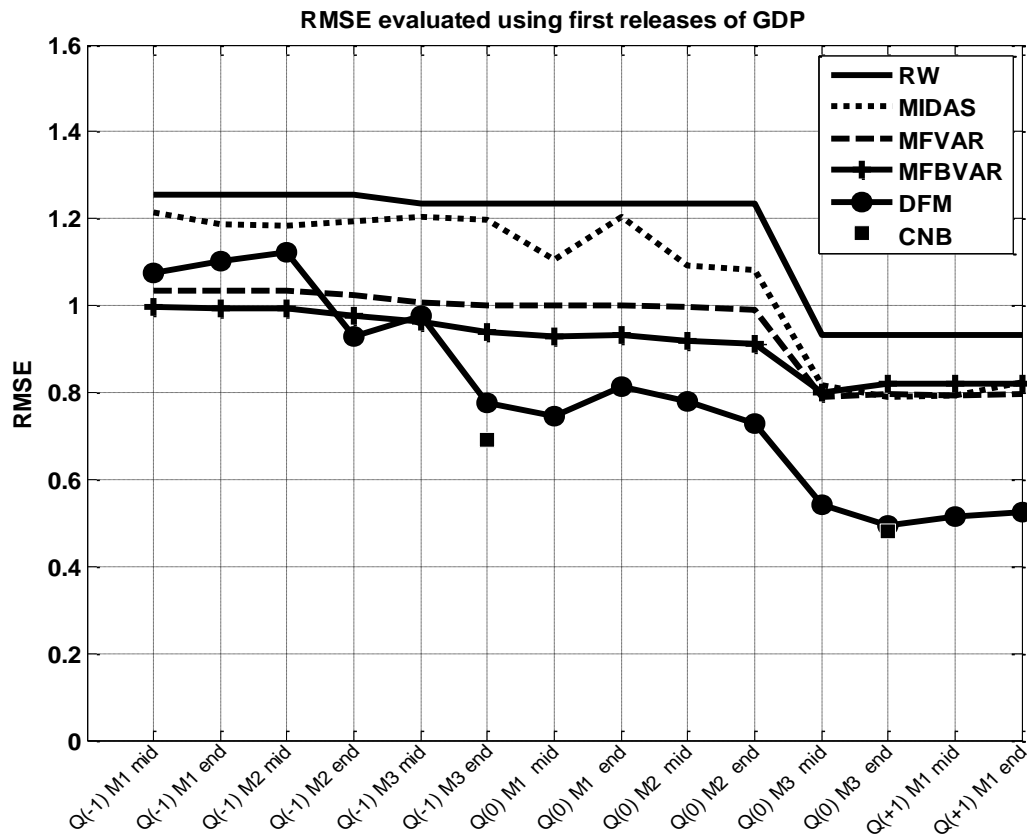
Notes: The nowcasting horizon (horizontal axis) refers to all the middles and ends of the months of the previous quarter: *Q(-1) M1 mid, Q(-1) M1 end, ..., Q(-1) M3 end*, to the same periods in the current quarter *Q(0) M1 mid, Q(0) M1 end, ..., Q(0) M3 end*, and to the middle and end of the first month of the quarter following the quarter the nowcast is done for: *Q(1) M1 mid and Q(1) M1 end.*

Regarding forecasting, at longer horizons (4 to 6 quarters) mixed-frequency VAR and the dynamic factor model deliver forecasts that are comparable to or better than the CNB forecasts. At shorter horizons, the CNB forecasts (up to 3 quarters ahead) perform best.

The forecasting performance exercise demonstrates that mixed-frequency data models are an important complementary tool to the currently used forecasting approaches, which often draw heavily on expert judgement. As mixed-frequency models take into account a much broader set of time series than single-frequency models, they can provide a similar level of forecasting quality as judgemental forecasts.

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The Effect of Non-linearity Between Credit Conditions and Economic Activity on Density Forecasts[2]

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A growing number of macroeconomic issues are being examined with the aid of density forecasts, i.e. the estimated probability densities of the future values of a random variable. For example, fan charts for inflation help the Bank of England communicate the direction and size of risks related to the inflation outlook (Britton et al., 1998). Next, predictive densities of macroeconomic variables allow for the assessment of the consistency and adverseness of macroeconomic scenarios underlying stress testing of the financial sector (Franta et al., 2014). Many applications of density forecasting can also be found in finance – for a selected survey see Tay and Wallis (2000).

Density forecasts are usually based on linear/linearised models. The reasons for this include the superior point forecasting performance of linear models and the computational feasibility of density forecast estimation. Imposing linearity on a macroeconomic relationship can, however, be misleading. A prominent example is the interaction between the financial markets and the real economy during the recent financial crisis. The profound fall in economic activity was not proportional to the original shock to the financial markets. Feedback effects arose between the financial markets and the real economy and affected the nature of the relationship. This non-linearity has been modelled using both structural models (Bernanke et al., 1996) and statistical models (Balke, 2000).

The effect of such non-linearity in the relationship between economic activity and credit markets on density forecasts is examined in Franta (2013). To that end, a threshold vector autoregressive (TVAR) model is estimated using Bayesian techniques and its density forecasting ability is compared to its linear counterpart. The real economy is captured by output, the short-term interest rate and inflation. The model is completed with a variable representing credit market conditions. The data set contains US quarterly data and covers the period 1984–2012.

It turns out that non-linear models can provide a more realistic tool for the probabilistic assessment of the macroeconomic outlook than linear models. The results suggest that for some periods ("normal" times), explicit modelling of non-linearity in the relationship between credit and economic activity does not necessarily improve the forecasting ability of the estimated density forecasts. This may be due to over-fitting and misspecification of the particular non-linear model as well as to the general absence of non-linear effects. However, during "stress" events such as the recent Global Financial Crisis (GFC) the probabilistic assessment of the economic outlook provided by the non-linear model outperforms the linear version of the model.

The following figure shows density forecasts generated by the models estimated on the sub-sample covering the period 1984Q1–2008Q2 and ex-post observed values of the endogenous

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[2] This article is based on Franta (2013).

variables. Density forecasts from the non-linear model are indicated by shades of yellow, while density forecasts from the linear version of the model are represented by red curves.

Figure 1. Density forecasts from VAR and TVAR models estimated on 1984Q1–2008Q2
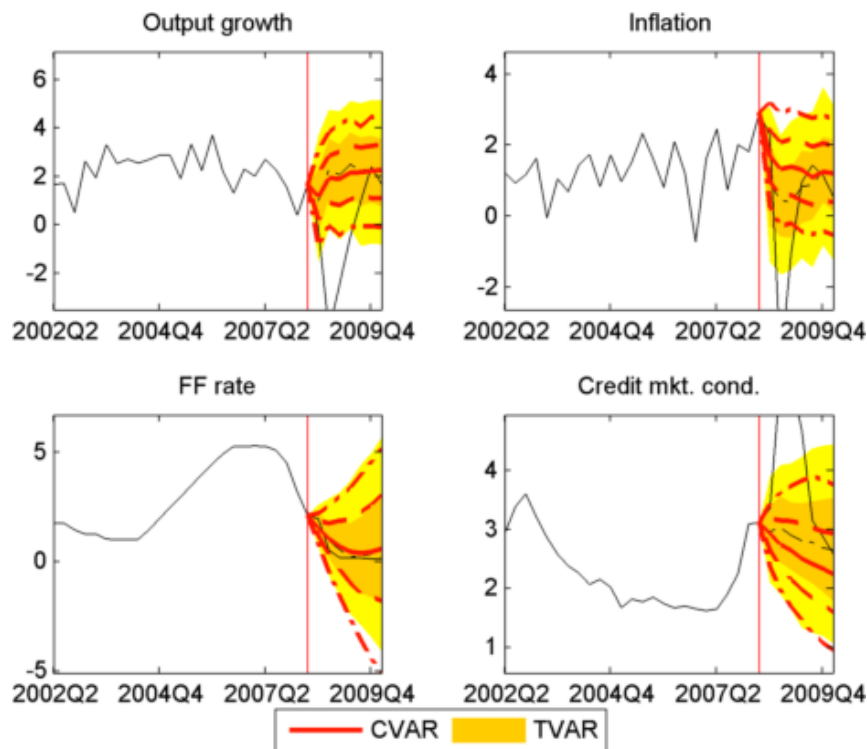
Notes: For the constant-parameter VAR (CVAR), the red curves indicate the median and the centred 68% and 95% of the density forecasts. For the TVAR, the median is denoted by the black dot-dash line and the centred 68% and 95% of the density forecasts are indicated by dark and light yellow. Observed data are denoted by a solid black line.

Figure 1 shows that the GFC is less surprising for the non-linear model. For some periods the non-linear model suggests a non-zero probability of an ex-post observed outcome which is estimated as a zero-probability event by the linear model (CVAR). It has to be stated, however, that this is not the case for all the zero-probability events suggested by the linear model.

Another issue that can be resolved using density forecasts is the likelihood of hitting the zero lower bound (ZLB) on the nominal interest rate. Chung et al. (2012) estimate the probability of hitting the ZLB for a set of structural and statistical models. In Franta (2013) their analysis is complemented by estimating the probability of hitting the ZLB based on TVAR and VAR models. The estimated probabilities build on models estimated on the sample 1968Q1–2007Q4 and suggest more realistic assessment of the ex-post observed periods of zero interest rates than the one presented in Chung et al. (2012). This is probably because estimates obtained from TVAR and VAR take into account parameter uncertainty. The estimated probability of hitting the ZLB for at least one quarter after 2007Q4 is around 0.1.

The conclusion that the TVAR model is appropriate for modelling "stress" events naturally implies a possible use of the model. Realistic modelling of stress events is a key element of stress testing of the financial sector. An advantage of the TVAR model is that the threshold variable that drives the regime of the system is endogenous. The explicit regime driver allows us to impose a

particular regime in the future. This can be done, for example, by soft-conditioning as introduced in Waggoner and Zha (1999). Such a procedure could be useful in the formulation of macroeconomic scenarios used in stress testing of the financial sector.

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Incorporating Judgements and Dealing with Data Uncertainty in Forecasting at the Czech National Bank[3]

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Model-based forecasts serve as important tools for the monetary policy decision-making process. In 2008, the Czech National Bank started using a dynamic stochastic general equilibrium model as its main forecasting and policy analysis tool (Andrle et al., 2003). Although the core model usually stands at the heart of each forecasting process, the forecast is not a simple "button-pressing" exercise, but is done iteratively by the forecasting team. There is always a trade-off between the size of a model and its tractability. A structural model should therefore capture the most important stylised facts about an economy and deliberately leave other data features outside its structure. During the forecasting process, the CNB forecasting team incorporates all relevant pieces of off-model information into the forecast to improve its reliability and acceptability for its users, mainly the CNB Board and the public. To achieve this, close cooperation between forecasters and sectoral experts and analysts is necessary.

This paper describes the forecasting process at the Czech National Bank, focusing on how off-model information is incorporated into the forecast. This process is illustrated by means of case studies. All examples of the incorporation of off-model information into the forecast presented in this paper reflect "real-life" issues addressed by the forecasting team when working on the CNB's predictions.

Before describing the selected case studies, the paper briefly provides an overview of the forecasting process at the CNB. The forecasting rounds consist of two – not strictly separated – steps. First, the initial conditions are identified to assess the position of the Czech economy in the business cycle and to evaluate the inflationary pressures. Second, the forecasts are produced based on the initial conditions, the outlook for exogenous variables and any off-model information available for the forecast horizon.

In cases where the forecasting team concludes that off-model expert information will capture the initial conditions more realistically, judgements are applied in order to identify structural shocks

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[3] This article is based on Brůha et al. (2013).

plausibly. An example of where the application of judgement is useful is an idiosyncratic wage increase or decrease due to factors such as tax optimisation or a change in statistical methodology. Such wage changes are unrelated to labour productivity or to inflationary wage-push shocks. Consequently, if such judgement is not used, the model might falsely identify such shocks, which would propagate to the forecast and policy recommendations.

The paper contains five case studies, but for the sake of brevity we choose to look at just two of them in this overview. The reader is referred to the original paper for the complete set of real-life examples and their detailed description.

The first case study involves the identification of the initial conditions concerning the link between the exchange rate and import prices, i.e. the identification of inflationary pressures stemming from import prices. During the Great Recession, the koruna-euro exchange rate depreciated significantly in 2008 Q4–2009 Q1. The main task associated with import prices during the April 2009 forecast was to assess the strength of the inflationary pressures stemming from imported goods. At the beginning of the crisis in 2008 Q4, the data indicated that importers had lowered their mark-ups relatively moderately. In 2009 Q1, however, the crisis fully hit the economy. In this situation, importers could hardly propagate the increased costs into their prices and they temporarily lowered their mark-ups. Although the 2008 Q4–2009 Q1 depreciation was unprecedented, historical experience (e.g. in 2003) indicated that significant depreciations had not fully transmitted to import prices.

Since the high value of the nowcast of the import price deflator in 2009 Q1 implied strong inflation pressure, the forecasting team decided to insert expert judgement implying lower inflationary pressures stemming from the import price deflator. From the ex-post point of view, the incorporation of this judgement was correct, as the forecast would otherwise have implied a counterintuitive reaction of the implied path of interest rates (i.e. a hike).

The second case study illustrates that a proper treatment of wage dynamics is one of the most important tasks during the forecasting process. This is because wage costs are key and persistent determinants of nominal marginal costs and thus of inflation developments. Nevertheless, there are issues, not explicitly accounted for by the model, which affect the observed wage dynamics in an important way and that have no fundamental impact on price developments. These include tax optimisation and the often countercyclical change in workers' sickness rates and the wage distribution across types of workers.

The forecasting team faced the following dilemma during the January 2010 forecast: the Czech economy was already in deep recession in 2009 Q3, year-on-year economic growth having reached -4.1%. A rapid decline in external demand had resulted in a deep fall of Czech investments and exports. Year-on-year growth in nominal wages and real household consumption had gradually been slowing. The October 2009 forecast, based on the cyclical position of the economy, assumed a further deceleration of nominal wage growth from 2.9% to 2.5%. The new data, however, indicated a sudden and significant year-on-year increase in the average nominal wage in the business sector to 4.2%.

To understand the main causes of the surprisingly high average wage growth in such an environment, sectoral specialists provided a detailed analysis of the latest labour market trends.

They identified two main factors behind the high average wage growth: an above-average fall in the sickness rate, and a wage distributional effect arising from the high share of low-pay workers among those who were being laid off. The two effects together had an estimated positive impact of 1.8–2.1 percentage point. This was reflected in the judgement on observed wage growth.

The monetary policy implications of the applied judgement were even more pronounced than in the previously discussed case of import prices. Compared with the simulation without judgement, the implied interest rates in the baseline scenario were lower for a period of more than six quarters, with the maximum difference reaching almost 0.5 percentage point in the third and fourth quarters of 2010. The judgement applied appears to have been correct from the monetary policy perspective in the ex-post view.

More than five years of DSGE-model-based experience with forecasting and policy analysis has enabled the CNB's forecasting team to accumulate experience with incorporating off- model information and judgement into a model-based forecast. The presented case studies describing the use of judgement in the CNB's forecasting process imply that close cooperation between sectoral specialists and the modelling team can result in an "integrated" forecast that reflects the information available from various sources in a balanced manner. From this point of view, applying expert judgement is a necessary part of each forecast to supplement the core model mechanisms. The expert judgements applied have often had an important direct impact on monetary policy decision-making. They have done so mainly in the direction of delivering more monetary policy easing during crisis times, which has proven to be correct from the ex-post point of view.

The paper may thus be useful not only to general readers who are interested in how the CNB's forecasts are actually made, but also to professional forecasters working with macroeconomic models, as the basic principles and lessons learned are applicable to forecasting based on structural macroeconomic models in general.

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Evaluating a Structural Model Forecast: Decomposition Approach[4]

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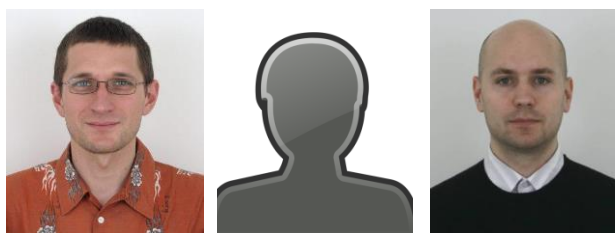
Inflation-targeting policy requires a good understanding of the role of the central bank in the monetary transmission mechanism. The Czech National Bank (CNB) devotes considerable intellectual activity and computational power to forecasting major economic variables, while no less effort is made to ensure that its monetary policy decisions are credible. Such credibility is gained from transparency of these forecasts. The CNB's official forecast is based on a structural model of a small open economy as described by Andrle et al. (2009). The forecast is conditional on observed data as well as additional assumptions covering the foreign economy, fiscal policy and administered price outlooks, the short-term forecast of the exchange rate and inflation, and expert judgement.

The forecasting framework processes newly available data and information updates through time, so it delivers a stream of forecasts. As these forecasts provide grounds for policy decisions, it is essential to evaluate their quality with respect to newly observed data and updated assumptions. The new analysis framework describes how changes in various subsets of newly collected information drive the update of the structural model forecast. This framework has been implemented into the CNB's regular forecasting process.

Figure 1 presents the general timing of two forecasts that enter the evaluation process. Both forecasts consist of two phases – identification of the cyclical position and prediction of variables. The aim of the analysis is to assess the quality of the Old forecast in light of the new information available at the time when the New forecast was created. We present the results of a real-life Inflation Forecast Evaluation exercise where the CNB's forecast released in Inflation Report I/2012 is evaluated with respect to the information available for the forecast released in Inflation Report III/2013.

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[4] This article is based on Brázdik et al. (2014).
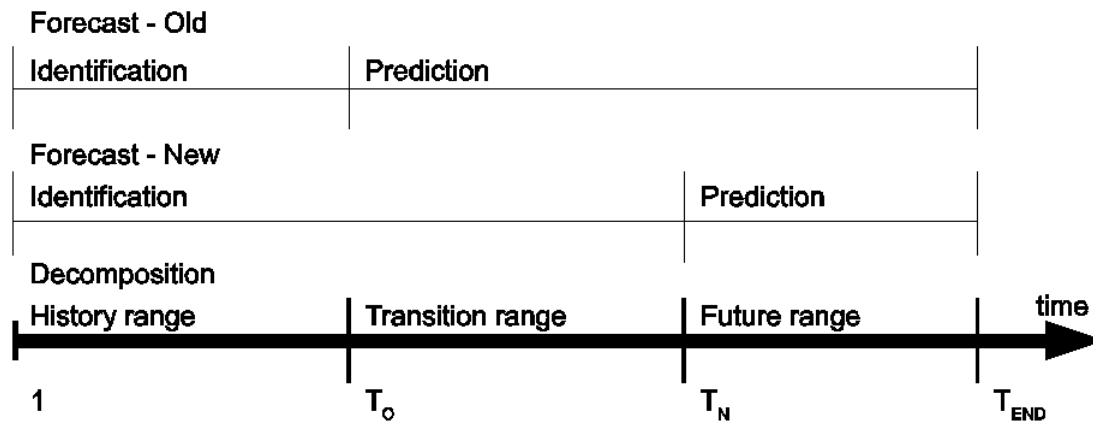
Figure 1. Forecast timing

Figure 2 presents the trajectories of the Old forecast (the blue line, Inflation Report I/2012) using the observed data up to the fourth quarter of 2011 (T_O), and the New new forecast (the red line, Inflation Report III/2013) created with the data up to the second quarter of 2013 (T_N). The graphs show the history range (the dark shaded area) up to period T_O, the transition range (the light shaded area) ($T_O + 1, T_N$) and the future range from period T_{N+1}.

Figure 2. Forecast evaluation – trajectories
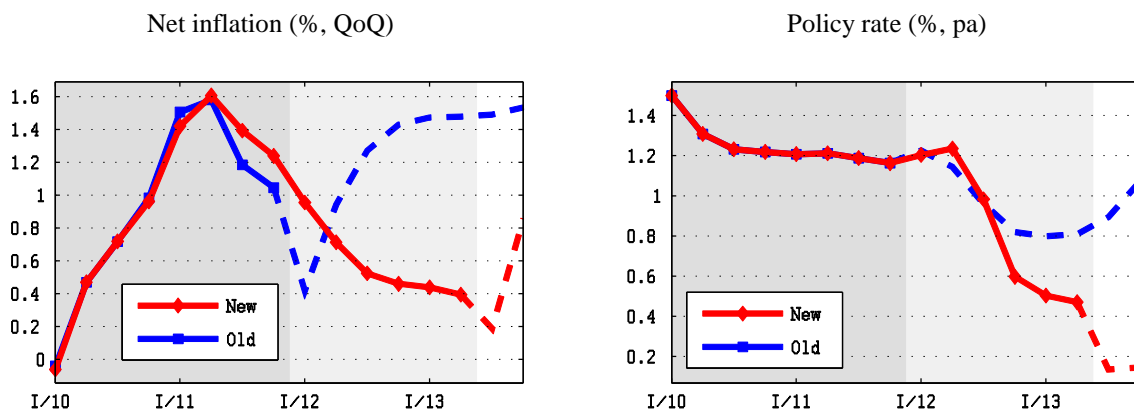
The Inflation Forecast Evaluation has two steps, as it considers two approaches for explanation of the variation between the projected trajectories and the data released over the transition range. First, the forecast update view is used. In this view, we explain the New–Old forecast difference with the updates in the assumptions that were imposed to create these forecasts. Second, the model dynamics are exploited to identify differences in structural shocks that the forecasters were not aware of at the time of the production of the Old forecast. These shock differences form the second group of factors, so the Inflation Forecast Evaluation is also able to offer a detailed view of the differences in the forecast trajectories through the differences in the shocks identified by the model.

Figure 3. Forecast evaluation – contributions

Net inflation (%, QoQ)   Policy rate (%, pa)
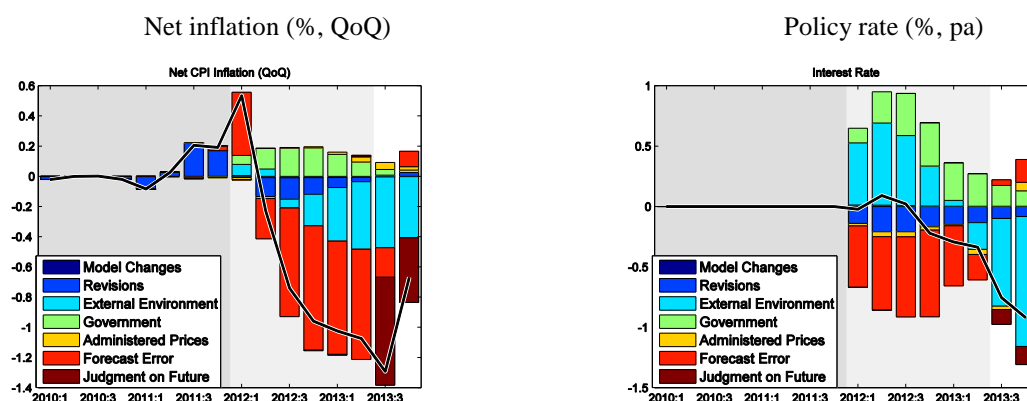
In the first step, the contributions of the ex-ante assumptions of the forecast are further divided into several subgroups as depicted in Figure 3. The standard groups are: model changes, data revisions on the history range, data release and the update of the outlook for exogenous variables (i.e. the external environment, government consumption and administered prices on the transition range and the future range). When updating the Old forecast with the new assumptions, forecasters are usually able to explain only a part of the variation between the Old forecast trajectories and the actually observed data; the unexplained part is referred to as the forecast error.

Figure 4. Forecast evaluation – missing structural shocks

Net inflation (%, QoQ)   Policy rate (%, pa)
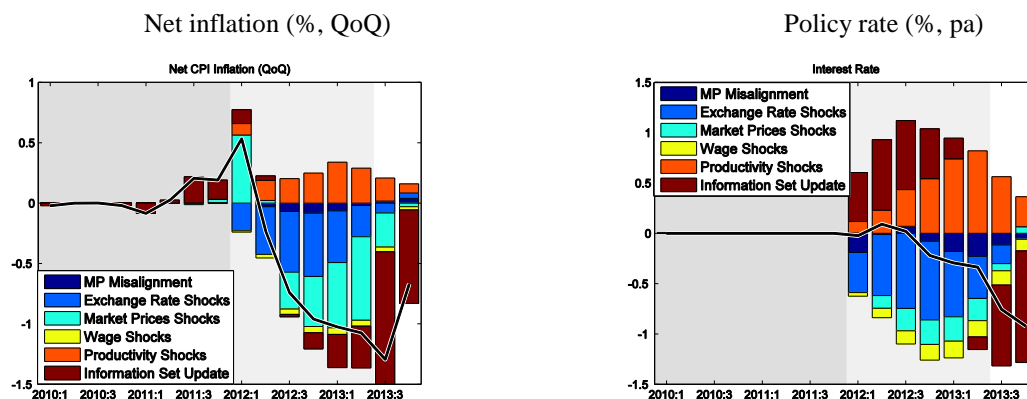
The second step of the evaluation focuses on explaining this forecast error in detail, using model dynamics to identify the structural shocks responsible for the deviations of the updated forecast from the actually observed data. These shocks are separated into six groups: monetary policy misalignment, an exchange rate shock (a shock to uncovered interest rate parity), price shocks (shocks to pricing mark-ups), wage shocks and technology shocks (shocks to productivity and shocks affecting supply). The sixth group in Figure 4 comprises the effects of the information set update. Thus, when comparing Figure 3 and Figure 4 we explain the same difference between the

actually observed data and the Old forecast (including the New forecast on the future range), but an alternative approach to understanding the forecast changes is used.

For the evaluation, we consider the structural shocks identified to be an indication of missing information from the ex-post view rather than forecasters' mistakes. Specifically, in the case of monetary policy, the presence of non-zero monetary policy shocks indicates too loose or too tight policy from the ex-post view. The preference for the missing information view is also supported by the fact that data collected in the evaluation period are subject to revisions.

The demanding part of the examination of missing structural shocks is to interpret those shocks and build a sound economic story based on the model mechanism. The decomposition results shown in Figure 4 indicate that monetary policy was slightly more contractionary than the model simulation would imply, as an (almost negligible) negative contribution of the policy shock (MP Misalignment) to the difference in net inflation is observed. The significant appreciation of the exchange rate in the first quarter of 2012 (Exchange Rate Shocks) contributed considerably to the low inflation. The presented decomposition results also indicate that the forecasters in the Old forecast were not expecting the negative shocks to prices (Market Prices Shocks) that were identified ex post when the New forecast was produced. The slowdown of the economy is consistent with the positive contribution of technology shocks to inflation, as the slower growth of productivity is not able to eliminate the growth in production factor prices. The decrease in productivity resulting from the economic slowdown (Productivity Shocks) is reflected in a negative contribution to wage growth.

We believe that the newly developed forecast evaluation methodology helps forecasters to improve future CNB forecasts by identifying the main sources of forecast errors and by teaching them more about the data and model properties. The Inflation Forecast Evaluation is an important exercise, as keeping track of the forecasters' actions enables them to reduce forecast error bias and prevents them from overreacting to noise in time series or anticipated events. The presented evaluation demonstrates the advantages of the implemented framework in the real-time forecasting exercise and supports our interest in decomposing and evaluating forecasts.

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Call for Research Projects 2016

The CNB Economic Research Department announced the Call for Research Projects 2016. Follow the link: http://www.cnb.cz/en/research/research_projects/call_for_projects_2016.html.

CNB Research Open Day

The eleventh CNB Research Open Day will be held in the Czech National Bank's Commodity Exchange (Plodinová Burza, Senovážné nám. 30, Praha 1) building on **Monday, 18 May 2015**. This conference provides an opportunity to see some of the best of the CNB's current economic research work, to learn about the CNB Call for Research Projects 2016 and to meet CNB researchers informally. The programme is available at:

http://www.cnb.cz/en/research/seminars_workshops/research_open_day_2015.html.