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Abstract

In response to the 2008 financial crisis, when policy rates hit their lower bound, central banks adopted unconventional policies to meet their announced targets. These policies can either directly target interest rates or the quantities of assets. Taking into account the specific features of the Czech economy, this paper presents an extension of the CNB's core projection model for long-term assets and yield curve control measures. This extension demonstrates the ability of the CNB to consider and assess various unconventional policies within its analytical framework.

Abstrakt

V reakci na finanční krizi v roce 2008, kdy měnověpolitické sazby dosáhly svých dolních hranic, začaly centrální banky pro plnění svých cílů využívat nekonvenční měnové politiky. Tyto politiky mohou být přímo zaměřeny na úrokové sazby nebo na množství aktiv. S přihlédnutím ke specifikům české ekonomiky představuje tento projekt rozšíření jádrového predikčního modelu ČNB o dlouhodobá aktiva a opatření typu řízení výnosové křivky. Tímto rozšířením prokazujeme schopnost ČNB zvažovat a hodnotit různé nekonvenční politiky s využitím svého analytického rámce.

JEL Codes: E32, E37, E43, E58.
Keywords: DSGE models, inflation targeting, quantitative easing, unconventional monetary policy, yield curve.

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1. Introduction and Motivation

In order to achieve their objectives, central banks face the challenge of demonstrating their readiness to react appropriately and in a forward-looking manner to ever-changing macroeconomic conditions. To address these new challenges, the Czech National Bank (CNB) and many other central banks act as centers of policy-oriented economic research where they innovate, amend their operations, and introduce new instruments and policy ideas. Central banks are not rigid and passive entities, quite the contrary. Such behavior has been even more apparent during the extraordinary periods over the past couple of decades. Recent policy innovations and the implementation of unconventional monetary policy (UMP) instruments have expanded the menu of policy options available to policymakers today.

Inflation-targeting monetary policy traditionally relies on controlling a short-term policy interest rate. Adjustments to this rate and expectations of its future settings are transmitted through multiple transmission channels into the effect it has on inflation. However, policy authorities can introduce UMP tools in response to conditions when the transmission of conventional monetary policy is distorted or not effective enough to achieve its goals. In recent times, UMP has been typically applied when monetary policy has come up against persisting disinflationary pressures requiring a further loosening of monetary conditions and conventional policy tools, i.e. the policy rate is at its effective lower bound. Further, UMP addresses distortions in the functioning of the policy transmission mechanism. In the presence of distortions, bypassing the traditional channels and applying UMP may present a viable solution.[1]

In general, UMP needs to be tailored to the conditions stipulated in the monetary and financial stability frameworks of the individual central banks. The prevailing economic characteristics and circumstances, technical feasibility, legal constraints, credibility and transparency, communication, expectations management, etc. also have to be taken into account. The choice of unconventional policy and the efficiency of each of the UMP tools considered is characterized by state dependency on the macroeconomic conditions. The application of UMP naturally requires the proper timing of its initiation, implementation and exit. This paper focuses on the application of UMP in the forecasting and policy analysis system (FPAS) of the Czech National Bank (CNB) taking into account the specific characteristics of the Czech economy.

This work introduces and evaluates yield curve control (YCC) measures as one of the possible UMP instruments that may be used by the CNB in practice. For this purpose, yield curve control policy has been incorporated into the CNB's forecasting framework by introducing the type of long-term assets in Falagiarda (2014) into the g3+ core projection model. The model, as introduced in Brázdik et al. (2020), has been extended in a straightforward and parsimonious way so it can be used for real time analytical and forecasting exercises. The structure extension can be flexibly adjusted and tailored to the parameters of the UMP programs implemented as specified by the CNB. We also consider the practical aspects of the potential implementation of the YCC program. The results and scenarios presented support the inclusion of a long-term assets-based UMP in the CNB's pool of available and effective monetary policy instruments. We demonstrate the CNB's readiness to use this UMP when specific circumstances arise.

Consequently, this paper supports the high level of transparency of the CNB's monetary policy by highlighting and explaining the role of UMP tools within the CNB's forecasting and policy analysis system. Although the CNB has used neither YCC nor QE so far, this does not preclude their appli-

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[1] For a schematic summary of the transmission channels see the Annex in Reserve Bank of New Zealand (2022a).

cation in the future. Despite the fact that the Czech economy and many other economies around the world are currently facing a period of high inflation, this work demonstrates the readiness and ability of the CNB to consider and assess various unconventional policies within its analytical framework. This ability is important for the monetary policy decision-making process as it is confirmation of a high level of flexibility in responding to specific economic developments and special circumstances.

The paper is structured as follows. Section 2 presents YCC policies in the context of UMP-related empirical literature and reviews the international experience with their application. Section 3 examines possible approaches to UMP modelling within a DSGE framework. Section 4 describes an extension of the CNB's projection model with YCC, while Section 5 describes the observed data and model calibration. In Sections 6 and 7, we introduce our model-based application of YCC and present the simulated effects of UMP. Counterfactual simulations of the CNB's exchange rate commitment and the Covid-19 period are shown in Section 8 and the last section summarizes our conclusions.

2. Yield Curve Control in the Context of Unconventional Monetary Policy

Although this work focuses mainly on long-term asset YCC programs, there are also other tools, or combinations thereof, that belong to the set of UMP tools. This set includes forward guidance, negative interest rates, extended-term lending operations, and others as listed in Reserve Bank of New Zealand (2022a).

Asset purchase programs or other programs aimed at lowering long-term yields comprise a variety of different measures and have been quite often implemented by, e.g. the ECB, the Federal Reserve System, the Bank of Canada, the Bank of England and Sveriges Riksbank, etc.[2] Such applications are documented in an international comparison of the impacts of QE during the recent COVID-19 pandemic, presented, e.g. in Rebucci et al. (2022). Also, Bernanke (2020) reviews the US Fed's experience with QE and forward guidance since the Great Recession.

Under these unconventional programs a central bank engages in large-scale purchases of government (and possibly private) assets, thus expanding its balance sheet. Contrary to conventional monetary policies directly affecting short-term interest rates, these UMPs are aimed at lowering the long end of the yield curve and thus easing monetary and financial conditions. In the case of QE, the central bank achieves the required reduction in the yield curve by purchasing bonds on the secondary market. Unlike for YCC, the target determining the purchases is not the price (or yield), but the volume of purchased bonds or other securities. The transmission mechanism effectively includes portfolio balancing, signaling and expectations (confidence) channels. The YCC introduced in this paper belongs to this group of UMP tools and is described in more detail in the subsequent sections.

The experience of the US Fed with the targeting of the yield curve in 1942–1951 is summarized by Chaurushiya and Kuttner (2003). The authors discuss the possible conflict that may arise between monetary policy objectives and interest rate targets. The rising inflation in 1950 and 1951 eventually led to the end of the YCC program and the related commitments on bond yields. Chaurushiya and Kuttner (2003) question the effectiveness of the YCC program in limiting private sector interest rates, mentioning the increase in spread between private securities and government bonds. With

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[2] Quantitative easing first appeared as a term in the early 2000s when the Bank of Japan rolled out this policy to fight domestic deflation. That said, some of the policies from the 1930s, used to fight the Great Depression, contained aspects of present-day QE programs. However, the adoption of QE on a truly large scale first emerged as a response by the US Federal Reserve in 2009.

respect to the exit strategy, they mention a bond conversion program that was put in place after the discontinuation of YCC in order to limit the losses for the bondholders and preserve the stability of the banking system. Finally, the authors also consider the impact of YCC on public debt financing, which may give rise to a conflict between the central bank and the fiscal authorities, especially about the precise timing of the exit.

The Bank of Japan is an example of the long-term application of YCC in practice. Hui et al. (2022) uses a target-zone model to study Japanese bond yields under the YCC program. The author identifies the spillover from the U.S. Treasuries to Japanese government bond yields. He also suggests that co-movements of the government bond yields can have an impact on the parameters of the YCC program in Japan, and especially on the adjustments of the target band.

Most recently, the Reserve Bank of Australia launched a YCC UMP program in response to the Covid-19 pandemic on March 19, 2020. Its experience is summarized in Reserve Bank of Australia (2022). The Australian implementation of this type of UMP was generally successful in reducing long-term bond yields (initially with three years residual maturity) and maintaining them near announced levels for a relatively long time. However, the faster-than-expected economic recovery and unexpected manifestation of strong supply-side cost pressures during 2021 necessitated an earlier exit from the YCC regime than initially anticipated. The Australian experience with YCC confirmed the feasibility of this type of measure in practice, but at the same time highlighted its risks and limitations.

The significant drawback of YCC is the need for either an implicit or even explicitly communicated commitment of the monetary authority related to the future evolution of the base rates as well as of the target bond yields. Due to the rather long residual maturity of targeted bonds, the horizon of the related forward guidance is naturally of a similar length. In the case of a sudden change in macroeconomic conditions, the monetary authority may face the difficult choice between keeping its promises and delivering adequate monetary conditions, i.e. the textbook time inconsistency issue. The Reserve Bank of Australia eventually recognized that its forward guidance was becoming untenable and decided to discontinue the YCC regime on November 2, 2021. Due to the rather abrupt nature of the exit and the fact it conflicted with the bank's previous communication, its credibility and reputation suffered to a certain extent. Based on the Reserve Bank of Australia's experience, perhaps the more state-dependent and time-limited nature of the YCC measures should have been communicated from the beginning, even if their effectiveness would have been somewhat reduced.

Another frequently discussed UMP approach relies on negative interest rates. A further lowering of the rates below zero adjusts long-term yields downwards in line with expectations of future short-term rates, thus providing the desired expansionary monetary stimulus to the economy. This instrument is listed among the UMPs as negative rate policies generate losses for liquidity holders when placing excess reserves with the central bank or depositing large amounts with commercial banks. The practical experience of various central banks (including the ECB, the Swiss National Bank and many others) and research by Arteta et al. (2016) and Boucinha and Burlon (2020) confirm the efficiency of this UMP. Using the negative interest rates tool as part of the CNB's forecasting framework may be applied almost instantly as the core projection model has no explicit constraints as regards the zero/effective lower bound for interest rates; theoretically the rates may drop as low as necessary. The modeling framework still relies on all the standard transmission channels – interest, credit and exchange rate. Negative interest rates were frequently discussed at the CNB during the exchange rate commitment in 2013–2017 and also during the Covid-19 pandemic.

The other set of UMP includes funding for lending, or in a broader sense expanded lending operations to financial institutions. In this case, a central bank extends the existing facilities or introduces new ones in order to provide more liquidity and loosen the lending conditions to support private banks' credit activity to the real economy. Such policy action is aimed at supporting credit flows to the private sector and impacts market expectations about interest rates. It is effective especially when standard monetary policy transmission is disrupted and in need of support.[3]

Although sometimes challenging under unforeseen circumstances, forward guidance is another effective UMP instrument. This is when a central bank increases transparency about its monetary policy by providing information about its future policy actions and intentions in order to impact market expectations. The communication of the central bank itself must be followed by actions supporting the credibility of its monetary policy and reducing uncertainties, as discussed in Bassetto (2019). Therefore, forward guidance is usually accompanied by other UMP instruments in order to increase its effectiveness and overall credibility. In the modeling framework of the CNB, forward guidance is applied via the expected outlook of monetary policy actions, using expected shocks in the simulation, as described in Musil et al. (2021).

The UMP toolkit may be further extended by various other measures ranging from exchange rate interventions (including an exchange rate commitment), applying inflation-targeting escape clauses, price level or average inflation targeting, or a more controversial change in the inflation target or even the concept of a helicopter drop of money.

Exchange rate interventions have a special position among these tools. In the case of the small, highly open and globally integrated Czech economy, the use of the exchange rate as an additional monetary policy tool, where the central bank transparently announces the level of the exchange rate to achieve and maintain, is proven highly efficient. The transmission of such policy is based on a chain, where a weakening of the exchange rate results in higher import prices, increased inflation expectations, lower real interest rates stimulating domestic demand, and higher sales on domestic and foreign markets due to increased Czech price competitiveness. The CNB has comprehensive experience with its exchange rate intervention policy in 2013–2017, see Franta et al. (2014), including the related amendments of its core projection model.

The aforementioned UMP instruments were discussed thoroughly at the CNB during the recent period of low interest rates and the economic slowdown sparked by the Covid-19 pandemic. There are several examples of the application of these policies all over the world in response to the global financial crisis and/or the Covid-19 pandemic. A discussion on the practical experiences of several central banks with UMP are summarized in detail e.g. in Potter and Smets (2019). Therefore, these considerations are not just a theoretical exercise but also serve to demonstrate the CNB's readiness to transparently apply new tools.

The rest of the paper focuses on UMP tools designed to deliver lower long-term yields, i.e. YCC in particular. A key distinction between YCC and QE is the economic aspect: whether the instrument has the character of a determined price (yield) or a determined volume of trades carried out by the central bank. When determining the price as a parameter of an UMP, a central bank has likely more

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[3] The international experience of expanded lending is described in Churm et al. (2015) for the Bank of England, or in Andreeva and García-Posada (2021) in the case of the ECB. In the Czech Republic, the government supported funding for lending through various assistance programs: COVID II, COVID Praha, COVID III, etc.

control over the economic effects of its operations. Thus, we focus primarily on YCC in the Czech macroeconomic environment.[4]

3. Approaching Unconventional Monetary Policy within the DSGE Models

Prior to the 2008 financial crisis, central banks had mainly operated within the short-term segments of the financial markets. However, the subsequent global economic slowdown led many central banks to reduce their short-term policy rates sharply. After the lower bound for their short-term instruments was reached, central banks resorted to unconventional monetary policies. Hence, policies like forward guidance and quantitative easing (QE) emerged to stimulate the economic system.

As Gertler and Karadi (2011) states, the literature on quantitative easing up to 2009 was more qualitative than structural. However, in the last 10 years, there has been considerable growth in the literature evaluating QE policies and their impacts. Many of these studies use Dynamic Stochastic General Equilibrium (DSGE) models and extend existing models by including various aspects of QE measures. After 2009, the development of structural macroeconomic models was aimed at extensions allowing for the quantitative analysis of unconventional monetary policy effects in the same general manner in which the frameworks in place before 2008 were able to study conventional monetary policies. Therefore, financial intermediation, new assets and structures, together with financial frictions, were added to conventional monetary policy models.

A stream of research inspired by the financial crisis of 2008 focuses on the role of financial intermediaries, such as Gertler and Karadi (2011), while other approaches introduce various financial assets, e.g. Andrés et al. (2004) and Falagiarda (2014). For models inspired by the 2008 crisis, it is natural to feature financial intermediaries' balance sheets. The usual symptoms of financial market disruption include a sharp rise in various key credit spreads as well as a significant tightening of lending standards.

To capture these crisis scenario features, Gertler and Karadi (2011) incorporate financial intermediaries into an otherwise standard macroeconomic framework. In general, the structure of these intermediaries is based on the work by Bernanke et al. (1999). Further, to capture unconventional monetary policy, Gertler and Karadi (2011) allows central banks to act as an intermediary by borrowing funds from savers and then lending them to investors at additional cost. Unlike private intermediaries, the central bank does not face constraints on its leverage ratio in the implementation of this role. Thus, QE can be modeled as the central bank's intervention to support credit flows in periods of financial distress when the cost of private financial intermediation is high.

QE approaches based on the financial intermediation framework of Gertler and Karadi (2011) are prone to limitations due to the assumption of transforming a central bank into an active financial intermediary. In addition, out-of-model considerations are stretched towards issuing risk-free government debt, which is often an unrealistic assumption. Moreover, the expectations of a central

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[4] In general, monetary policy is most effective if it works through all the transmission channels in the same direction at the same time. Limitations on a certain channel thus mean lower effectiveness of monetary policy overall. This opens the scope for combining some of the tools with each other leading to positive synergic effects or the elimination of some negative side effects. For example, negative interest rates can be suitably combined with YCC (or QE) and forward guidance, which together would help to effectively transfer negative (or very low) interest rates to the longer end of the yield curve. However, a proper combination of these UMP tools is a topic for an optimal policy mix and decision and is beyond of the scope of this work.

bank intervention may spark various moral hazard implications for private intermediaries that are not included within this framework.

An alternative stream of QE modeling considers the introduction of new assets that differ in maturity. This is in contrast to the arguments presented by Moore (1988) that the supply of credit money is endogenously determined by demand, and only its price, not its quantity, can be controlled by the central bank. The quantitative easing policies that are currently implemented build on the arguments supporting the assumption that credit supply can be controlled to a reasonable extent by a central authority. Therefore, New Keynesian literature started to explore portfolio choices where, by changing the desired proportions of different assets, the prices of long-term bonds will adapt to those of short-term bonds influenced by the central bank. The common feature of this stream is the presence of imperfect substitutability. Various assets like deposits, government securities and currency holdings are present within this design. This stream stems from the contribution of Andrés et al. (2004) who presented a dynamic version of financial system design by Tobin (1969).

The rationale for imperfect substitutability between various assets originates from the transaction cost motive, where asset rebalancing is subject to adjustment costs. The details of why assets of different maturities may be imperfect substitutes are not usually formally modelled.

Andrés et al. (2004) developed a New Keynesian model with explicit imperfect substitutability where the expansion of the supply of one asset affects both the yield on that asset and the spread or “risk premium” between returns on that asset and alternative assets. In this model, the time-varying transaction costs and the presence of risk on the long-term bond market are the source of imperfect substitutability.

Similarly, in the context of QE in the US, Chen et al. (2012) present an extended conventional DSGE model with purely exogenous transaction costs for long-term bonds. A risk premium is also introduced, as in Andrés et al. (2004). Chen et al. (2012) find that the effects of asset purchase programs on macroeconomic variables, such as GDP growth and inflation, are likely to be modest. The authors also conclude that asset purchase programs are effective in stimulating the economy. In this case, the effect on the real economy arises because of the presence of limits to arbitrage and market segmentation between short-term and long-term government bonds. Kortelainen (2020) used the Chen et al. (2012) model to explore extending the effects of the APP in the euro area. The author concludes that YCC can be an effective unconventional monetary policy tool if implemented credibly and for a long enough period.

The stylized New Keynesian model extended for imperfect substitutability between short-term and long-term bonds is used by Harrison (2012) to study optimal policy. The introduction of imperfect asset substitutability provides an additional channel through which the policymaker may stabilize the economy. However, Harrison (2012) points out that it also creates a new distortion that the policymaker should aim to offset (changes to asset purchases can affect real economic activity).

Further, Falagiarda (2014) adopts a portfolio adjustment cost friction that resembles the model setup of Chen et al. (2012) for an analysis of QE in the US and the UK. This model exhibits imperfect asset substitutability between government bonds of different maturities. Imperfect substitutability is generated through the introduction of portfolio adjustment frictions. As a result, the model is able to isolate the portfolio rebalancing channel of quantitative easing.

The CNB’s approach to UMP modelling, which was developed and considered in 2012, was based on introducing long-term interest rates into the otherwise standard structure of the central bank’s core forecasting model (then the g3 model). The related monetary policy experiments relied heavily on the use of forward guidance. For more details, see Appendix A.

When considering the international dimension of studies, most of the literature focuses on large economies. Almost all of the early studies are focused on closed economy models and the early applications include Dedola et al. (2013) which is an open economy extension of Gertler and Karadi (2011) for studying the role of monetary policy cooperation for economies of equal size. The small open economy applications, such as Hohberger et al. (2019), have only recently been popping up.

This review shows that there is a set of diverse approaches to the implementation of UMP tools within the DSGE framework. For the purposes of regular forecasting exercises at the CNB we sought an implementation that is flexible, operable and practical. In the following section, we go on to describe our preferred approach.

4. Extending the CNB's Core Forecasting Model with Yield Curve Control

In order to implement yield curve control (YCC) as unconventional monetary policy in the FPAS of the CNB, we investigate a model-consistent approach based on the core prediction model. The model extension presented in this paper builds on Falagiarda (2014)[5] by introducing long-term bonds into the core model and creating a portfolio rebalancing channel. This extension makes the real economy sensitive to unconventional monetary policy tools such as YCC.[6]

The CNB's core forecasting model, currently represented as the g3+ model by Brázdik et al. (2020), is a small open economy DSGE model with a semi-structural foreign block representing the effective euro area.[7] The production side of the domestic economy consists of intermediate goods producers and final goods producers of GDP components. Intermediate goods producers use capital and labor as their production factors. Final goods producers combine domestic intermediate goods with imported energy and non-energy imported goods in their production function. The monopolistic market structure for all goods allows producers to maintain a positive markup when prices are sticky.

The model economy is populated by typical Ricardian households with full access to the financial markets and "hand-to-mouth" non-Ricardian households. A simple government consumption rule is assumed to represent fiscal policy. The monetary authority follows the rule focused on the forecasted inflation targeting rule with policy smoothing. The model is closed by an uncovered interest parity condition driving the path of the exchange rate while taking into account the foreign unconventional monetary policy. The model economy also includes several technological processes able to describe sectoral productivities that are driven by exogenous processes. These productivities also fit the stationary model to the observed data while taking into account the structural relationships of the relevant model variables.

The applied approach abstracts from the inclusion of the complete yield curve at all the underlying maturities, i.e. the whole term structure. It rather assumes that the information about the long end

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[5] A similar approach has been applied repeatedly in the literature, see for example Harrison (2012).

[6] Apart from the portfolio rebalancing channel, the literature describes other transmission channels through which the YCC takes effect in the economy. These channels are also present to a certain extent in the model concept that is described here (fiscal channel or signaling channel). Other channels (the credit channel or liquidity premium channel) are less important in the conditions of the Czech economy, where a surplus of liquidity is typical.

[7] The effective euro area represents the euro area economies weighted by their respective shares in Czech exports.

of the yield curve can be concentrated in a single point – be it a particular maturity or a (weighted) average of maturities.

4.1 Households

Our model extension and adjustment of the current g3+ model focuses on the introduction of long-term assets available to households with access to financial markets. Two bonds of different maturity are now available to households which can deposit their savings into or borrow against these bonds. Therefore, besides the standard short-term bond B_t with a rate of return of i_t, the budget constraint newly includes long-term bond $B^H_{L,t}$ holdings with a long-term rate of return of $i_{L,t}$:

$$\frac{B_t}{P_t i_t} + \frac{B^H_{L,t}}{P_t i_{L,t}}\left(1 + AC^L_t\right) + \cdots \quad = \quad \frac{B_{t-1}}{P_t} + \frac{B^H_{L,t-1}}{P_t\, prem^{LB}_t} + \cdots, \tag{1}$$

while the rest of the budget constraint is the same as in the g3+ model presented by Brázdik et al. (2020).

In Falagiarda (2014), the returns on long-term bonds are discounted only by a short-term interest rate no matter the specific maturity of the long-term bonds in question. Our extension newly allows for more model flexibility in the matching structure of financial markets when considering the yields of short and long-term assets. Therefore, the g3+ model extension presented in this paper includes the introduction of an exogenous time premium $prem^{LB}_t$ used in the long-term bonds return discounting and linking to the short-term interest rate i_t as follows:

$$\log(prem^{LB}_t) \quad = \quad \rho_{prem^{LB}} \log(prem^{LB}_{t-1}) + (1 - \rho_{prem^{LB}}) \log(\overline{prem^{LB}}) + \varepsilon^{prem^{LB}}_t \tag{2}$$

where $\rho_{prem^{LB}} \in [0,1]$ is premium persistence and $\varepsilon^{prem}_t \sim N(0, \sigma^{prem^{LB}})$.

The model structure does not pre-determine the duration of the long-term bonds. Therefore, the steady-state premium $\overline{prem^{LB}}$ can be calibrated according to the choice of maturity of representative long-term bonds by using the following relation:

$$\bar{i}_L \quad = \quad \bar{i} \cdot \overline{prem^{LB}}, \tag{3}$$

where $\bar{i}$ and $\bar{i}_L$ are steady-state values of short-term interest rate i_t and long-term interest rate $i_{L,t}$.

Households prefer to maintain a pre-determined ratio between their holdings in the form of short-term bonds and long-term bonds. Any deviation from this portfolio ratio imposes additional costs. The real portfolio adjustment costs AC^L_t are defined with respect to the size of the economy Y_t:

$$AC^L_t \quad = \quad \left[\frac{\phi_L}{2}\left(\kappa_L \frac{B_t}{B^H_{L,t}} - 1\right)^2\right] Y_t, \tag{4}$$

where $\kappa_L, 0 < \kappa_L < 1$ represents the preferred ratio of long-term bonds $B^H_{L,t}$ to short-term bonds, B_t. Here, the elasticity of portfolio adjustment costs ϕ_L scales the overall impact of the portfolio structure changes into the real economy. [8]

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[8] The real portfolio adjustment costs could be expressed with respect to the amount of private consumption as an alternative measure of the size of the economy. However, the main driver of the adjustment costs AC^L_t should be the portfolio composition change, i.e. the ratio of short and long-term bonds held by households.

As in Falagiarda (2014) and Chen et al. (2012), we also follow Andrés et al. (2004) and assume a degree of segmentation of the financial market. In line with the preferred habitat theory[9], we postulate that investors have heterogeneous preferences for short- and long-term assets, e.g. pension fund regulations that set requirements to hold long-maturity assets or government bonds. Thus, the short and long-term assets are no longer perfect substitutes. In the structural implementation, the presence of these frictions leads to the presence of portfolio adjustment costs and it enables the returns on the long- and short-term assets to endogenously deviate from each other, i.e. the endogenous part of the term premium appears.

The presence of portfolio adjustment costs implies that changes in the bonds' portfolio composition affect the optimization behavior of households and their utility. This implication makes the long-term interest rates relevant to the macroeconomic development. As a consequence of adding the long-term bonds $B^H_{L,t}$ into the decision problems of households, the intertemporal optimality condition[10] with respect to standard short-term bonds B_t is modified and takes on the following structure:

$$\beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}} = \frac{\lambda_t}{i_t} + \frac{\kappa_L \phi_L \lambda_t Y_t \left(\kappa_L \frac{B_t}{B^H_{L,t}} - 1\right)}{i_{L,t}}, \tag{5}$$

while an additional condition was introduced into the model structure as follows:

$$\beta E_t \frac{\lambda_{t+1}}{\pi_{t+1} prem^{LB}_t} = \frac{\lambda_t}{i_{L,t}} + \frac{\phi_L \lambda_t Y_t \left(\kappa_L \frac{B_t}{B^H_{L,t}} - 1\right)^2}{2 i_{L,t}} - \frac{\kappa_L \phi_L \lambda_t Y_t B_t \left(\kappa_L \frac{B_t}{B^H_{L,t}} - 1\right)}{B^H_{L,t} i_{L,t}}, \tag{6}$$

where λ_t is a Lagrange multiplier corresponding to the budget constraint, β is the discount parameter, and π_t is the rate of consumer price inflation. In the steady state, the bond portfolio structure is in line with the preferred ratio of long and short-term bonds κ_L and the portfolio adjustment costs are equal to zero.

Further, Equations (5) and (6) imply the steady-state relation of the long- and short-term rate as presented in Equation (3). However, whenever the bond portfolio composition deviates from the preferred ratio, the difference between the long-term and short-term rate is driven above or below the exogenous time premium $prem^{LB}_t$.

4.2 Emission of Bonds and Asset Purchases

In the extended model, short-term bonds B_t and long-term $B_{L,t}$ bonds are issued by the government. The emission of long-term bonds $B_{L,t}$ is given exogenously. As in the original g3+ model, the short-term bonds B_t are given endogenously by balancing the income and expenses of the government.

Thus, the aggregate government and central bank budget constraint is as follows:

$$\frac{B_t}{P_t i_t} + \frac{B_{L,t}}{P_t i_{L,t}} + \frac{\Delta_t}{P_t} = \frac{B_{t-1}}{P_t} + \frac{B_{L,t-1}}{P_t prem^{LB}_t} + G_t - T_t, \tag{7}$$

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[9] For more details see Koeda and Ueno (2022), where the preferred habitat term structure model is extended to analyze YCC by treating the Bank of Japan as the preferred habitat investor.

[10] Familiarly known as Euler's equation.

where government spending G_t and the lump-sum transfers T_t are balanced by a change in the value of long-term bonds on the central bank's balance sheet (net long-term assets purchases) Δ_t and bond holdings change.

The government lump-sum transfers T_t are given by the actual outstanding government debt and its steady-state values:

$$T_t = \psi_0 + \psi_1 \left(\frac{B_{t-1}}{P_t} - \frac{\overline{B}}{\overline{P}} \right) + \psi_2 \left(\frac{B_{L,t-1}}{prem_t^{LB} P_t} - \frac{\overline{B}_L}{\overline{prem^{LB} P}} \right) \tag{8}$$

where ψ_0 is the steady-state level of transfers T_t, ψ_1 and ψ_2 are elasticities to deviations of real bond holdings from their steady states.

Of the total amount of long-term bonds, $B_{L,t}$, the central bank holds the share of $x_t, x_t \in [0,1]$. The remaining share $(1-x_t)$ of bonds is held by households:

$$B_{L,t}^{CB} = x_t B_{L,t} \tag{9}$$

$$B_{L,t}^{H} = (1-x_t) B_{L,t} \tag{10}$$

The central bank does not control the exogenously given total amount of bonds issued in the economy. The central bank applies unconventional monetary policy by trading the existing stock of long-term bonds $B_{L,t}$ and keeping it in its balance sheet. Changes in the amount of long-term bonds held by the central bank x_t are expressed in nominal terms by variable Δ_t:

$$\frac{\Delta_t}{P_t} = -\left(\frac{B_{L,t}^{CB}}{P_t i_{L,t}} - \frac{B_{L,t-1}^{CB}}{P_t prem_t^{LB}} \right). \tag{11}$$

The changes in x_t driven by the central bank induce adjustments in households' portfolios, from which the central bank buys or sells the bonds in the first place. Further, these adjustments in the volume and prices of long-term bonds $B_{L,t}$ induce real economy responses.

4.3 Uncovered Interest Rate Parity Condition

In the baseline g3+ model, the exchange rate equation[11] takes into account the interest rate differential of the short-term interest rate i_t and the foreign interest rate i_t^*. However, when considering the application of the YCC policy, it is plausible to assume that the ELB constraint will be binding for the domestic short-term interest rate i_t. Therefore, the exchange rate response may be missing the direct effects of monetary expansion delivered by the YCC measures.

The foreign monetary policy rate $i_{shadow,t}^*$ in the g3+ model already includes the effects of foreign UMPs, while the foreign short-term $i_{euribor,t}^*$, represented by the 3-month EURIBOR rate, may be subject to ELB. To represent the rate prevailing at the foreign exchange markets, the representative interest rate i_t^* is defined as follows:

$$\log(i_t^*) = w_{shadow} \log(i_{shadow,t}^*) + (1-w_{shadow}) \log(i_{euribor,t}^*), \tag{12}$$

where $w_{shadow}, w_{shadow} \in [0,1]$ is the weight of the foreign monetary policy interest rate representing the composition of assets traded at the given rate.

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[11] Derived from uncovered interest parity condition, therefore known as the UIP equation.

To cope with the missing direct link in the UIP relation, we extend the domestic side of the UIP condition by adding the long-term rate $i_{L,t}$. Consistent with the foreign economy, we define the domestic foreign exchange rate i_t^{UIP} as the weighted average of short and long-term rates:

$$\log\left(i_t^{UIP}\right) = w_{i^L}\log(i_{L,t}) + (1 - w_{i^L})\log(i_t), \tag{13}$$

where $w_{i^L}, w_{i^L} \in [0,1]$ is the share of assets traded at the domestic long-term rate $i_{L,t}$.

We replace the UIP condition of the g3+ model by:

$$\log\left(i_t^{UIP}\right) = \log(i_t^*) + \rho_s dep_{t+1} - (1-\rho_s) dep_t + 2\cdot(1-\rho_s)\overline{dep} + \log\left(prem^{UIP}\right) + \varepsilon_t^{UIP}, \tag{14}$$

where the nominal exchange rate depreciation of the koruna with respect to the euro dep_t reflects changes in interest rates considered at foreign exchange i_t^{UIP} and i_t^*, the endogenous risk premium $prem_t^{UIP}$ and subject to i.i.d. exchange rate shocks $\varepsilon_t^{UIP}, \varepsilon_t^{UIP} \sim N(0, \sigma^{\varepsilon^{UIP}})$. In this case, $\overline{dep}$ is the steady-state depreciation rate of the CZK, and ρ_s represents the forward-lookingness of the UIP condition.

Based on this new model extension, the exchange rate directly responds to the changes in domestic unconventional monetary policy. The calibrated values ensure that easing the domestic monetary policy stance via UMP (i.e. the buying of public bonds as part of a YCC program aimed at yield to maturity reduction) leads to koruna depreciation.

4.4 Monetary Policy

For the purposes of practical application in monetary policy decision-making, the model was extended with an unconventional monetary policy rule for a long-term interest rate.[12] Also, as McGough et al. (2004) note, shifting from the use of a short-term rate to a long-term rate as the monetary policy instrument raises indeterminacy issues. Indeterminacy arises because many possible future paths for the short-term rate may be consistent with a given setting of the long-term rate.

When considering scenarios, the typical solution to the presence of indeterminacy is to assume that a clear signaling and communication strategy about the central bank's intended path of the short-term rate is associated with the long-rate monetary policy response. To guarantee the tractability of the model in general, we take into account the conclusion by McGough et al. (2004) that the problem of indeterminacy can be avoided if the long-rate monetary policy response is explicitly forward-looking.

In the extended model, the inflation targeting regime remains the main objective of the central bank. In the case of a YCC regime, it is favorable to choose an interest rate rule analogous to the original monetary policy rule with a short-term interest rate.[13] Therefore, the unconventional monetary policy rule also targets the expected deviation from the inflation target $\hat{\pi}_{t+4}$ and the calibration of its parameters is the same:

$$\log i_t = \rho^M \log i_{t-1} + (1-\rho^M)(\log i_t + \psi \log \hat{\pi}_{t+4}) + \varepsilon_t^M + \varepsilon_t^{MS}, \tag{15}$$

$$\log i_{L,t} = \rho^M \log i_{L,t-1} + (1-\rho^M)\left(\log i_{L,t} + \psi \log \hat{\pi}_{t+4}\right) + \varepsilon_t^M + \varepsilon_t^{ML}, \tag{16}$$

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[12] i.e. the rate of return on the long-term bonds. Also note, that unlike in the original paper, the share of long-term bonds held by the central bank, x_t, is endogenous.

[13] In the g3+ model, the three-month PRIBOR rate is used as an observed representation of the modeled short-term rate.

where i_t represents the short-term policy rate (3-month PRIBOR) and i_t^L is the long-term interest rate (the rate of return on the long-term bonds). Both rules assume interest rate smoothing described by parameter $\rho^M, 0 < \rho^M < 1$ and elasticity to deviation from the target $\psi, \psi > 1$.[14]

To allow the modelling features of the yield curve under unconventional monetary policy, the set of structural monetary policy rules and monetary policy shocks is modified as follows:

- A standard monetary policy shock ε_t^M, familiar from the g3+ model, is preserved. As it now appears in both of the monetary policy rules, it is responsible for parallel shifts in the whole yield curve. We can take advantage of this feature to identify shocks that occurred in the past, when the CNB did not perform such unconventional monetary policy and long-term interest rates were a latent component of the transmission channel.
- A short-term monetary policy shock ε_t^{MS}, that affects only the short-term interest rates was added to the standard monetary policy rule. This shock is used to implement conditioning on the presence of the effective lower bound for short-term interest rates. This shock is able to affect the slope of yield curve.
- A long-term monetary policy shock ε_t^{ML} is defined in the unconventional monetary policy rule. It directly affects long-term interest rates only. Therefore, it can be used in simulations of YCC measures to condition on the trajectory for the long-term interest rates. This partial shock would mainly affect the slope of the yield curve.

In the extended model, the implementation of the YCC regime via interest rates (price of assets) is straightforward when following the endogenous response of the long-term rate rule as guidance for the unconventional monetary policy set-up. However, if asset purchases were applied as a policy tool (quantity of assets) and the monetary policy regime were to go more in the direction of QE, the proposed concept would be applicable with minor implementation changes.[15]

5. Observed Data, Calibration and Treatment of Expectations

The use of long-term bonds as an unconventional monetary policy tool should be viewed as an extension of the standard monetary policy set-up. In the standard inflation targeting setup, the central bank controls the interest rate for very short maturities (two weeks directly, three months on a market basis), i.e. at the short end of the yield curve. In extraordinary times, it may be necessary to have a closer grip on the yield curve. Therefore, it is natural to extend control towards long maturities in order to influence the interest rates relevant for corporate lending and thus influence the economic situation and ultimately the inflation expectations.

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[14] For the sake of the flexibility of the framework, the calibration of the parameters in both rules can be set differently. The symmetrical calibration is not a necessary condition.

[15] When applying QE, the monetary authority focuses on the share of long-term bonds held by the central bank x_t as the policy instrument. The long-term bond return and the central bank's share in the bond market are closely intertwined in the model. The endogenous response of the volume of long-term bonds as suggested by the long-term interest rate rule will be the policy guide. Further, this framework makes it possible to design the monetary policy rule for the QE regime. One can use the share of long-term bonds held by the central bank x_t as an explicit monetary policy tool:

$$\log x_t = \log x_{t-1} + (1-\rho^x)\psi^X \log \hat{\pi}_{t+4} + \varepsilon_t^X, \tag{17}$$

characterized by volume smoothing by $\rho^x, \rho^x \in [0,1]$ and the elasticity to inflation deviation $\psi^X, \psi^X < 0$.

5.1 Government Bond Yield as an Observed Variable

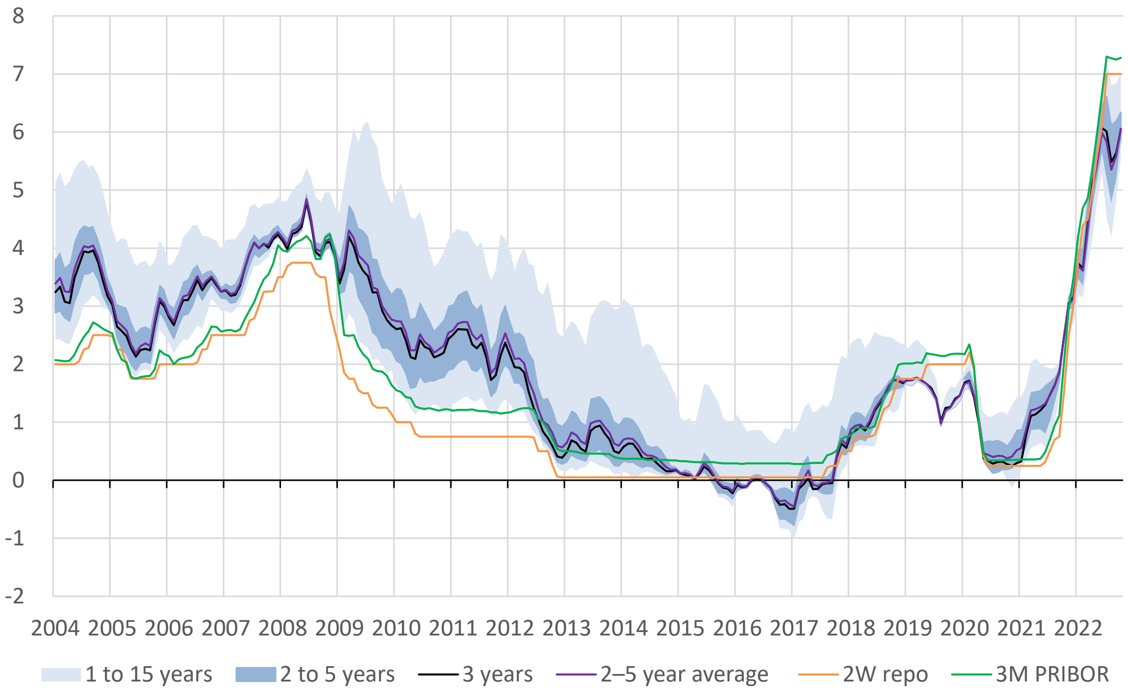
In order to fit the prediction framework to data, the model representation of the long-term yield $i_{L,t}$ has to be linked to the observed variable. The use of the long-term government bond yield as an observable proxy is based on the abstraction of considering firm-specific risk premia. The choice of maturity for this kind of proxy is based on the following motivation.

The central bank controls the short end of the yield curve by setting its main policy rates and thus directly influencing the 3M PRIBOR. The CNB also transparently communicates the short-term interest rate forecast path over the entire forecast horizon, which is at least two years. In addition to the current policy setup, the central bank can express its policy intentions over the medium-term future (e.g. in the form of forward guidance). Therefore, our experience suggests that the CNB can indirectly influence yield for assets with maturities of up to two years. These two policy measures can influence the medium-term market expectations and can be used to steer the short end of the yield curve.

However, in order to influence the distant components of the yield curve, these conventional measures might prove too weak. Therefore, an additional monetary policy tool may be necessary to pursue the central bank's goals. In order to influence the financing conditions of domestic firms, our expertise suggests the 2–5 years segment of the yield curve as an appropriate choice.

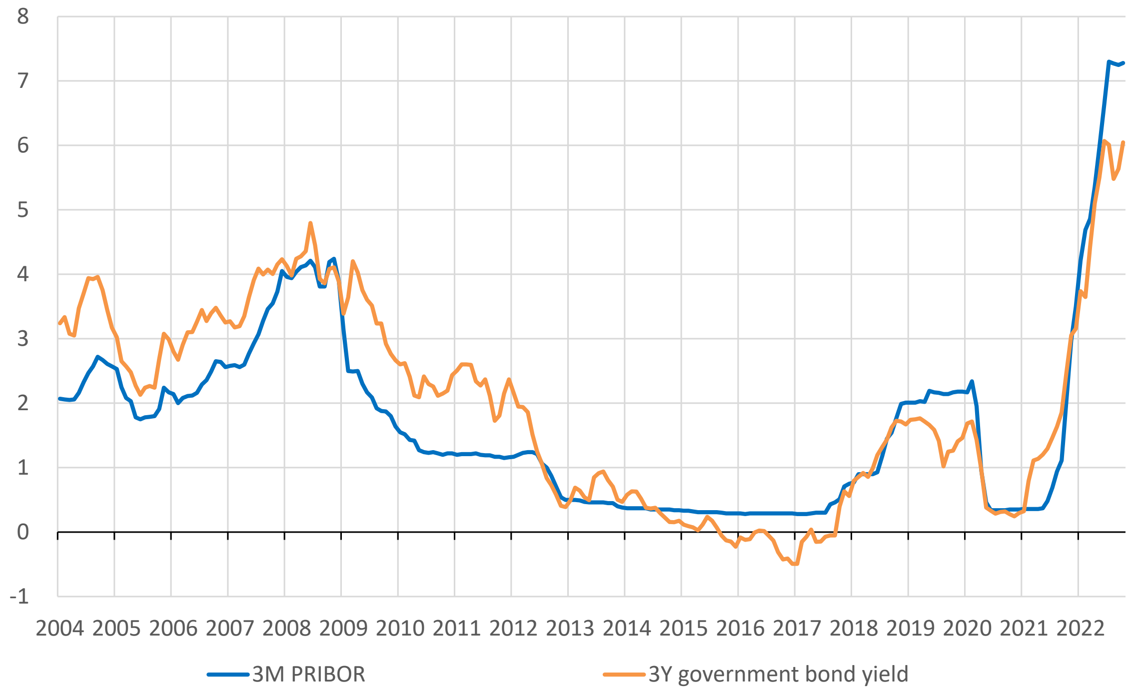
We prefer to avoid the use of bonds with maturities of beyond this segment. Long maturities of approximately 10 years or beyond cease to be relevant for firms. Such maturities are relevant for the mortgage market, making them interesting from the financial stability rather than the monetary policy perspective.

Figure 1: Government Bond Yields Comparison by Residual Maturity (%, p.a.)



Source: CNB, ARAD database

Figure 2: 3M PRIBOR vs. 3Y Government Bond Yield (%, p.a.)



Source: CNB, ARAD database

Figure 1 shows the history of the Czech government bond yield with a focus on medium-term maturities. It illustrates the development of the three-year government bond yield in comparison to the average yield of the whole 2–5 years segment. Note that the three-year bond yield very closely matches the overall dynamics of the whole 2–5 year segment. Due to this relationship, the three-year government bond yield is our preferred choice of representative observation of the medium-maturity segment of the yield curve in the extended model (see Figure 2). For more information about the historical development of domestic bond market yields, see Appendix B.

In addition to the considered price of the long-term bond $i_{L,t}$, the volumes of the bonds $B_{L,t}$, $B^{CB}_{L,t}$, and $B^{H}_{L,t}$ can be considered as an observed characteristic. However, from the perspective of the YCC regime, the volume variable is not as crucial as the long-term bond yield $i_{L,t}$. Also, traded bond volumes are not a reliable indicator of UMP activity due to institutional restrictions.[16] Therefore, we avoid using bond volumes as the observed variable when fitting the model to the data.

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[16] The Czech bond market is quite shallow and illiquid – the volume of the overall available stock of bonds is estimated at around CZK 1,000 billion. A large share of government bonds is held by institutional investors who are bound by regulation to hold low risk assets in their portfolio. Therefore, the asset purchases of the central bank would consist mostly of bonds held by foreign investors. Actually, only a fraction of the total bond market can be considered as stocks readily available for asset purchases – we believe as little as CZK 100 billion. This suggests that the bond market response to central bank purchases in terms of bond yields could be quite strong, non-linear and not easy to predict. On the other hand, the volume of bonds the central bank needs to purchase to achieve the desired change in the long-term bond yields may be quite small. Therefore, we have decided to focus on the intermediate target, which is the long-term bond yields. The implications for the bond volumes and their share held by the central bank x_t are drawn based on endogenous model mechanisms and serve only as a guideline for the central bank's asset purchases when applying QE monetary policy.

5.2 Calibration of Model Parameters

Our calibration of the newly introduced model dynamics parameters is summarized in Table 1. The rest of the new model parameters are calibrated in accordance with the steady-state properties of the domestic economy. We use Falagiarda (2014) as a guideline for these calibrations. However, some characteristics of the Czech economy are taken into account as well.[17] There is noticeable uncertainty surrounding the values of several newly introduced model parameters. The literature review currently forms the main basis for the choice of calibrated values.[18]

The portfolio adjustment costs elasticity ϕ_L is calibrated to a value of 0.005, which is close to the values of approximately 0.01 found in the literature. Our estimation attempts reveal that there is not much information in the data to pin down the value of ϕ_L – the posterior mean remains close to the prior mean. We attribute this to the CNB's low activity in the bond market in the past. More support for the estimated value should arise after the unconventional measures in the bond market are launched and more data is collected.

The weight of long-term interest rates in the exchange rate equation w_{i_L} is set to 40%, the short-term interest rate accounts for the remaining 60% weight.[19] Under this calibration, the short-term interest rate i_t remains the dominant domestic factor in the UIP condition given by Equation 14.

Table 1: Calibration of Model Parameters

Parameter		Value
Elasticity of portfolio adjustment costs	ϕ_L	0.005
Fiscal rule elasticity to short-term bonds	ψ_1	0.7
Fiscal rule elasticity to long-term bonds	ψ_2	0.7
Persistence of long-term bond emission	ρ_{BL}	0.9
Persistence of long-term bond premium	$\rho_{prem^{LB}}$	0.75
Weight of long-term interest rate in UIP	w_{i_L}	0.4

5.3 Treatment of Expectations

The transparent application of the YCC-type measures will require the communication of goals and the tools applied. Such an announcement can take the form of a commitment to interest rate trajectories as part of an introduction of this UMP. Moreover, a balance sheet analysis reveals these operations even without an explicit public announcement.

Therefore, it will not be viable to avoid anticipated monetary policy shocks. These anticipated shocks will originate from conditioning on a binding ELB constraint for short-term interest rates,

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[17] Several of the parameters introduced should be flexibly adjusted in accordance with the final design of the YCC program to be launched.

[18] In the Czech economy, unconventional monetary policy of this type has not previously been executed. Moreover, the Czech bond market is rather shallow and its liquidity is limited. The calibration of certain parameters will have to be adjusted after the launch of this type of unconventional monetary policy program. It is also quite possible that the bond market will react in a non-linear and discontinuous manner. In such a case, it will also be appropriate to reevaluate certain model parameters on a regular basis.

[19] This calibration reflects the expert opinion of our colleagues from the Financial Markets Department at the CNB. Qualitatively, it is similar to the calibration of the foreign counterpart of the UIP condition in the g3+ model, given by Equation 14, where the shadow rate weight *w_shadow* is set to 0.2, while the foreign financial market rate $i^*_{euribor,t}$ has a weight of 0.8 following the scheme given by Equation 12.

or on the announced path for the long-term interest rates committed to under YCC policy or representing a type of forward guidance policy. In the CNB's forecasting framework, we distinguish between an unrestricted (FIRE, full information rational expectations) and restricted (LIRE, limited information rational expectations) approach to modelling the anticipated shocks, see Musil et al. (2021). The LIRE approach to introduce assumptions conditioning into the CNB's forecasted trajectories is a standard part of g3+ model forecasts.

Unlike the very standard FIRE approach, the LIRE approach enables us to impose ample restrictions on the timing and visibility of anticipated information in the forecast. When simulating the YCC measures under the assumption of fully anticipated shocks, the forward guidance puzzle usually emerges, see Del Negro et al. (2012).[20] Under the LIRE approach, the anticipated future monetary policy shocks affect the decision-making of households and firms only when they are close enough. The LIRE approach structurally reduces the problem of forward guidance puzzle emergence. Therefore, the LIRE approach to expectations is used and appropriate expectation schemes were defined for the monetary policy shocks.

6. Role of Interest Rate Shocks in the Model – Impulse Response Analysis

To evaluate the dynamic properties of the extended model, Figure 3 shows a comparison of the impulse responses to monetary policy shocks $\varepsilon_t^M, \varepsilon_t^{MS}, \varepsilon_t^{ML}$ as defined in Equations 15 and 16. These impulse responses are based on same-size shocks in terms of interest rate change – 1 percentage point in annual terms.

The standard monetary policy shock ε_t^M, which delivers a parallel shift of the yield curve by design, has the most pronounced effects in terms of the exchange rate and CPI inflation. This is because the representative domestic interest rate i_t^{UIP} on foreign exchange markets, which determines the interest rate differential vis-á-vis the external economy in the uncovered interest parity condition, shifts in one-to-one proportion. The implied increase in the domestic-foreign interest rate differential then drives the appreciation of the domestic currency against the euro and CPI inflation dips by approximately 0.2 percentage point.

The responses to the specific monetary policy shocks ε_t^{MS} and ε_t^{ML}, that affect the short-term or only the long-term interest rate separately (change in the slope of the yield curve), reveal two notable results – both intuitive.

First, the model impulse responses show the interaction of two active monetary policy rules. In response to the short-term monetary policy shock ε_t^{MS}, the long-term interest rate $i_{L,t}$ declines by approximately 0.3 percentage point to compensate the short-term restrictive impact on CPI inflation. However, in the case of the long-term monetary policy shock ε_t^{ML}, it is the short-term interest rate i_t that declines by about 0.2 percentage point in order to compensate the restrictive effects of the one percentage point increase in the long-term interest rate.

Second, the impulse responses to the short and long-term monetary policy shocks ε_t^{MS} and ε_t^{ML} show weaker impacts on the economy. In the case of "yield curve slope shocks", the weighted interest rate i_t^{UIP} responds less than in the case of a "yield curve shift" kind of shock. Thus, the foreign-domestic

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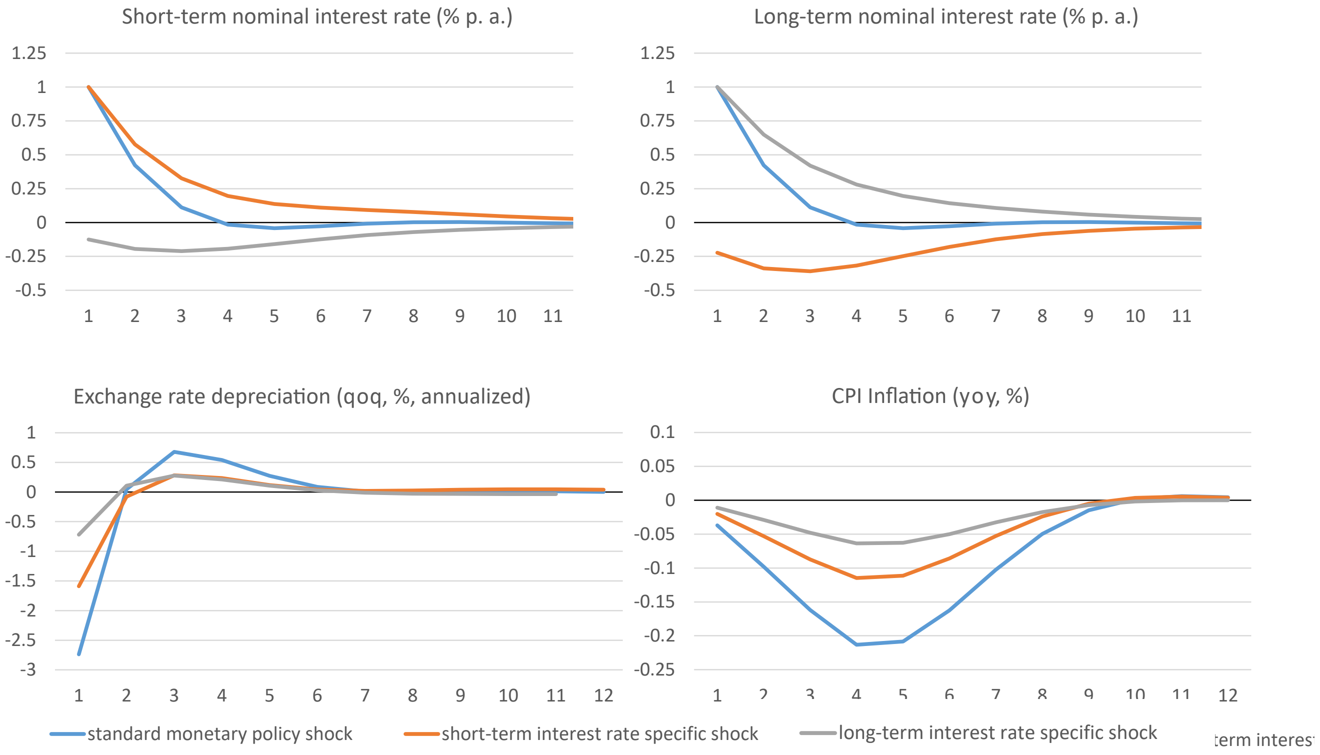
[20] The forward guidance puzzle refers to the ability of the anticipated shocks taking place further into the near future to induce strong immediate effects, usually at the start of the forecast horizon. Such behavior may often be seen as non-intuitive – e.g. the expectation of an event in the future can have a stronger impact than a realization of the same event now.

Figure 3: Impulse Responses to Interest-Rate Shocks (steady-state deviations, pp)



Source: Authors' simulations

interest rate differential does not increase as much. This results in a less pronounced exchange rate appreciation and CPI inflation dips only by about 0.1 percentage point in the case of a short-term interest rate shock, and by about 0.05 percentage points in the case of a long-term interest rate shock.

Also note that only short and long-term monetary policy shocks ε_t^{MS} and ε_t^{ML} are able to affect the slope of the yield curve in the model. None of the "standard" structural macroeconomic shocks in our model has any effect on the term premium of the long-term bonds $prem_t$. Therefore, they induce an endogenous monetary policy reaction along the whole yield curve.

The impulse responses presented in Figure 3 describe economic behavior that corresponds to cases in which the central bank can use both monetary policy rules simultaneously to steer inflation back to the target (i.e. the ELB does not apply). However, the YCC model framework will typically be used in a situation where the use of short-term monetary policy interest rates i_t will be limited by the ELB, while endogenous policy simulation would indicate values below the ELB.

Conditioning simulation on a binding ELB constraint will result in the presence of positive monetary policy shocks to the short-term interest rate. Applying the knowledge of the impulse responses presented, see Figure 3, it can be inferred that positive short-term interest rate shocks simultaneously imply that further monetary policy easing must be delivered via the long-term interest rate. Conversely, a negative shock in the long-term rate creates an opportunity for a tighter setting of the short-term interest rate in comparison to the case of a non-binding ELB constraint. We thus conclude that the extended model behavior is qualitatively consistent with the assumption of the application of unconventional monetary policy measures via YCC.

7. Simulated Effects of Yield Curve Control Measures

Prior to the initiation of YCC, the parameters of such a program have to be discussed. The following exercise evaluates the degree to which the extent of the expected effects of YCC is dependent on the length of such a program. For this evaluation, Table 2 shows a comparison of the simulated impact of a long-term bond yield reduction of 1 percentage point for 2 to 8 quarters.

The effects presented here are expressed as differences from the baseline scenario without YCC measures. These differences are either calculated for CPI inflation and the exchange rate at the monetary policy horizon (i.e. one-year ahead or t+4) or for GDP, private consumption and nominal wages in the first year from the launch of YCC (expressed at annual frequency).

Commitment versus the endogenous response of a long-term policy instrument is assessed along the expected (announced measures) and unexpected (unannounced) long-term bond yield dimension reduction. In this assessment, the endogenous response of the short-term monetary policy rate [21] is prevented as we assume a binding ELB constraint for the short-term interest rate.

Table 2: YCC Program Comparison by Length (yoy growth differences as against the baseline scenario in pp for the exchange rate in CZK)

Program	Monetary policy horizon*		First year after the launch		
Duration	CPI Inflation	Exch. rate (lev.)	GDP	Private consumption	Nominal wages
unannounced					
2 quarters	0.1	0.0	0.1	0.0	0.1
4 quarters	0.2	0.1	0.1	0.1	0.1
announced					
2 quarters	0.2	0.1	0.1	0.1	0.1
4 quarters	0.4	0.2	0.2	0.1	0.2
6 quarters	0.8	0.5	0.3	0.2	0.4
8 quarters	1.1	0.8	0.3	0.3	0.5

* Note that a standard monetary policy horizon of 12–18 months is assumed.

A reduction in long-term bond yields $i_{L,t}$ via the YCC program eases monetary conditions. This unconventional measure causes the exchange rate to depreciate and CPI inflation to increase at the monetary policy horizon. Private consumption, GDP and nominal wage growth in the first year after the launch of the program also increases in comparison to the baseline scenario.

When considering program duration, simulation results confirm that the short-term impacts can also be magnified by prolonging the duration of the program. These effects can be further magnified by the announcement of a credible commitment to the total duration of the program.[22] The longer the program duration, the greater the effect of the program. Such results are consistent with the previous

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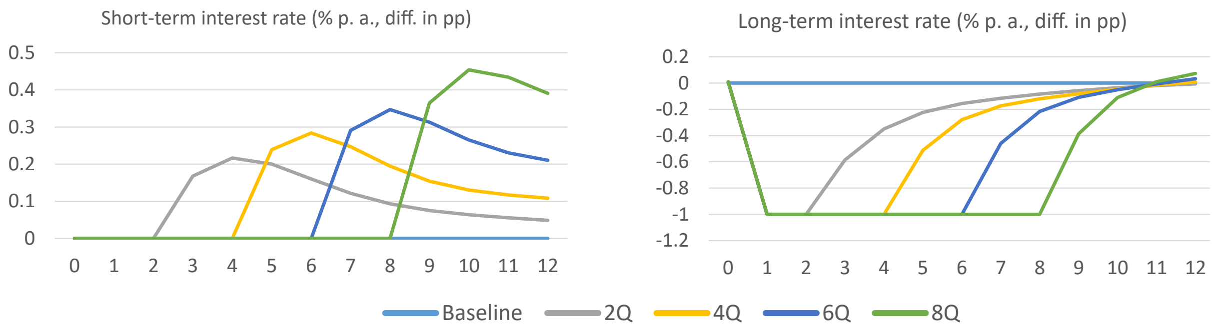
[21] The standard monetary policy rule remains active in the model. In reaction to monetary easing via long-term rates, it would imply simultaneous tightening using a short-term rate. This effect was prevented in the simulations.

[22] Please note that the impact of unannounced measures of longer than 4 quarters at the MPH (or in the first year after the launch of the measures) would be exactly the same as if these measures were in place for precisely 4 quarters. This is because the fact that the measures continue into another period is perceived as a surprise by the model agents in the simulation. Prolonging the program on an ad-hoc basis (e.g. after the previously announced program has already ended) cannot change the impacts generated by the measures taken so far. The development of economic variables in the first year after the launch of considered policy measures can be influenced by prolonging

experiences related to forward guidance. We also find this result intuitive. When economic agents know that the long-term interest rates are to remain lower for an extended period, they ceteris paribus take on more debt as against when they only learn about the lower interest rates on a quarterly basis.

Figure 4: Exiting YCC Programs by Duration Commitment



Source: Authors' simulations

To provide more details on the elasticity of the policy response to the announced program duration, a comparison of the simulations in Figure 4 presents the responses of the policy rate after the YCC program is exited. This comparison reveals that the longer (announced) duration of the YCC program, ceteris paribus, leads to steeper subsequent monetary policy normalization and exit from the YCC program, i.e. an increase in short-term interest rates (from the effective lower bound). This conclusion also holds for the long-term policy interest rates thereafter. This corresponds to greater overall monetary easing delivered by longer-lasting YCC programs. The interest rates can be increased faster and to higher values immediately after the YCC program has been terminated, thus fostering confidence in policy normalization.

It is natural to scale the effects of YCC by increasing the extent of the long-term bond yield reduction. We do not report these results as this is a linear operation in the presented framework.

8. Counterfactual Simulations Using Yield Curve Control

We illustrate the current implementation mechanisms of the unconventional monetary policy tool presented here by means of hypothetical simulations based on the prevailing macroeconomic conditions in the Czech Republic in the period under review. During this period, the macroeconomic forecast indicated the need for negative short-term interest rates for an extended period of time. These exercises are based on following the likely sequence of steps leading to the actual launch of the YCC program:

1. The core prediction model repeatedly indicates the need for a large and long-lasting reduction in the main policy rate into negative territory.
2. The Bank Board or the Monetary Department decides to prepare an alternative scenario to the baseline forecast scenario, where long-term interest rates will be used as a monetary policy tool (YCC scenario).

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the horizon beyond the original one (a MPH of one year) only when these measures are announced from the beginning in a credible manner. This is also the reason Table 2 only contains the impact of unannounced programs with a duration of 2 and 4 quarters, while the longer programs lasting 6 and 8 quarters are also reported for announced measures.

3. The initial condition of the extended g3+ model forecast scenario (presented above) will be set so as to imply a similar trajectory for the short-term interest rate as that of the standard g3+ model. Simultaneously, this provides forecasters with an endogenous trajectory for the long-term interest rates $i_{L,t}$.
4. Using the short-term interest rate shock ε_t^{MS}, the short-term interest rate trajectory will be fixed at the predetermined effective lower bound (zero lower bound, last value). The unconventional monetary policy rule for $i_{L,t}$ would indicate necessary additional easing in terms of the long-term interest rate.
5. If the target value for the long-term interest rate were to be publicly announced (e.g. in the form of a commitment), the long-term monetary policy shock ε_t^{ML} would be used to condition on the given long-term rate trajectory.

8.1 Exchange Rate Commitment Counterfactual Scenario

This scenario demonstrates an alternative to the choice of monetary policy in 2013 when the ELB constraint was binding. The baseline scenario indicated the need for a reduction in the base rate to values around -0.5% for several quarters. The Czech National Bank decided to launch its exchange rate commitment policy.[23]

This exercise shows the implications of replacing the exchange rate commitment with a YCC commitment of various strengths. The results of the alternative simulations based on the extended g3+ model are shown in Figure 5. In the simulation of alternative scenarios, we assume ex ante projected trajectories of the main macroeconomic variables as published in the forecast in Inflation Report IV/2013, i.e. the situation in late 2013, see Czech National Bank (2013).

First, the free simulation (blue line) in Figure 5 is a replication of the baseline scenario from Inflation Report IV/2013. Based on this replication, the endogenous response for setting the long-term policy rate $i_{L,t}$ indicates a decrease close to the zero lower bound.

Further, conditioning the simulation on keeping the short-term interest rate i_t at 0.5%, through the application of a standard monetary policy shock ε_t^{M} demonstrates the implications of too tight monetary policy imposed along the whole yield curve. As the IR fix simulation via application of standard MP (red line) show, there is no policy easing using long-term interest rates. In this case, the monetary authority fails to ease monetary policy appropriately using interest rates as a tool. This differs quite substantially from the free simulation – the difference in CPI inflation at the monetary policy horizon compared to the free simulation would amount to 1 pp

However, a binding constraint on the short-term interest rate can also be delivered using a short-term monetary policy shock ε_t^{MS} as IR fix with a specific MP shock fix simulation (red line) shows. The endogenous response of the long-term interest rate UMP tool implies a considerably less restrictive impact of a binding effective lower bound for a short-term rate. The endogenous trajectory of the long-term interest rate in this simulation bottoms at around -0.5%, while the difference in CPI inflation at the monetary policy horizon against the free simulation is approx. 0.2 pp This additional easing of monetary policy under YCC policy also significantly changes the slope of the yield curve.

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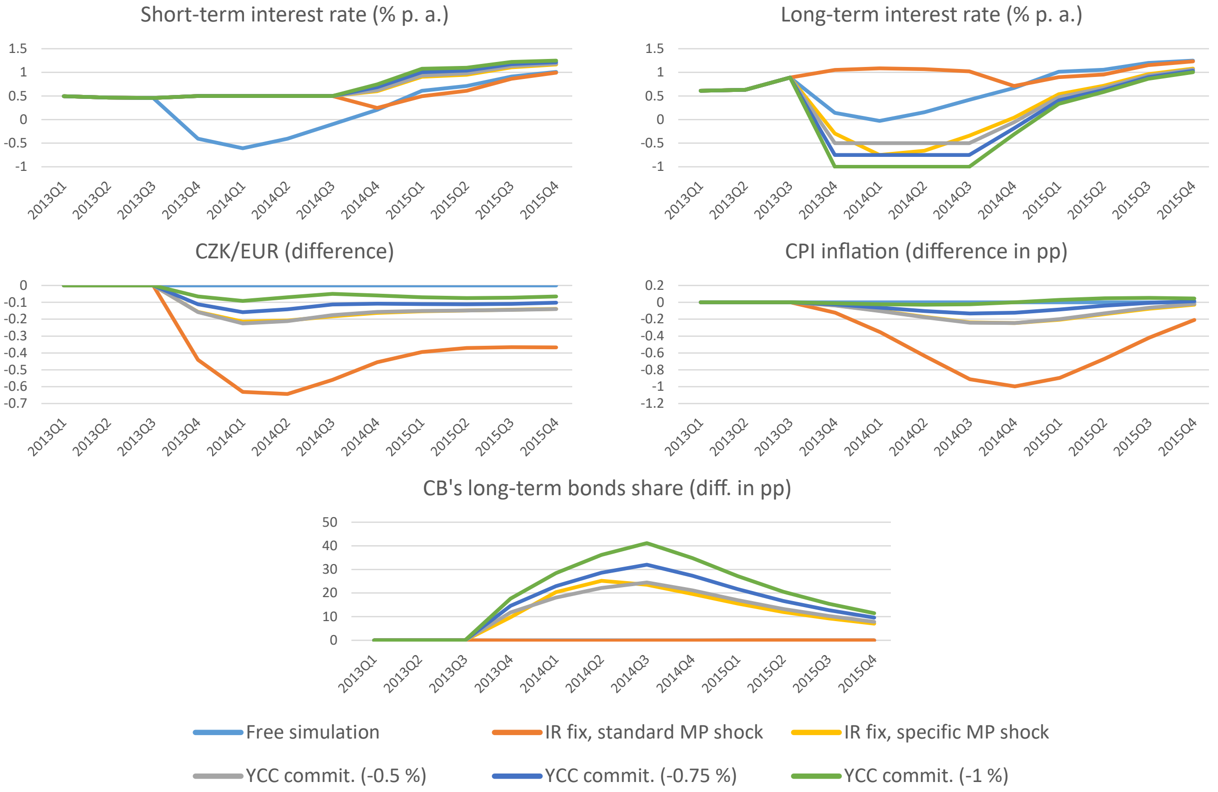
[23] The Czech National Bank announced an asymmetric commitment to intervene against the domestic currency in order to keep it above the floor of CZK 27 to the euro. A minimum duration of the commitment was also announced, but the eventual exit from the non-standard monetary-policy regime was left open-ended. Over time, the duration of the program was prolonged several times. See Czech National Bank, Inflation reports (Czech National Bank (2013) through Czech National Bank (2017)).

Figure 5: Counterfactual Scenario of Applying a YCC Program in 2013 with a Stable Short-Term Interest Rate of 0.5 %



Note: The free simulation depicts an unrestricted model consistent with monetary easing. IR fix simulations show the effects of a restriction imposed on the short-term interest rate with the use of either a standard MP shock ε_t^{M} (shifting the whole yield curve) or a short-term MP shock ε_t^{MS} (shifting only the short end of the yield curve). YCC simulations show the results of YCC programs at different levels of long-term interest rate with an announced duration.

Source: Authors' simulations

Optionally, monetary policy easing under YCC can be delivered in the form of a commitment to various levels of the long-term rate $i_{L,t}$. A commitment to long-term interest rates over a one-year period at a level slightly below the endogenous trajectory is simulated via the long-term policy shock ε_t^{MS}. The YCC commitment simulations show that such policies are able to deliver a very small deviation of CPI inflation from the free simulation. Apparently, the endogenous reaction of the long-term interest rate cannot completely eliminate the restrictive effect of a binding constraint for a short-term rate at 0.5%. Nevertheless, this type of simulation serves as a useful starting point for the assessment of the level of the long-term interest rate commitment for the actual application of YCC.

The YCC simulations presented in Figure 5 also reveal the corresponding changes in the volume of long-term bonds held by the central bank. The results of these simulation suggest that the monetary authority would have to purchase approximately 25 to 50% of the total volume of long-term bonds in the economy over a period of one year.[24]

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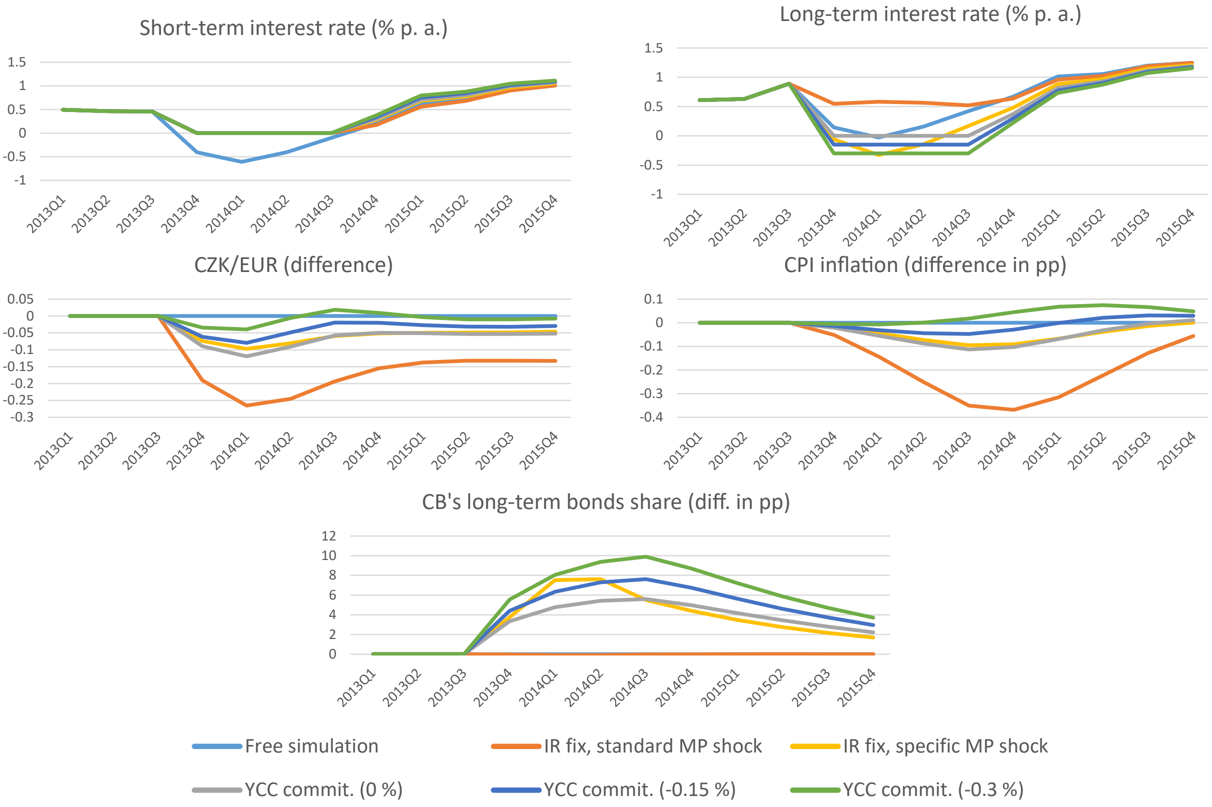
[24] Such a response provides useful guidance even in cases where an asset purchase program is used (QE).

Figure 6: Counterfactual Scenario of Applying a YCC Program in 2013 with Short-Term Interest Rate at Zero (ELB)



Note: The free simulation depicts an unrestricted model consistent with monetary easing. The IR fix simulations show the effects of a restriction imposed on the short-term interest rate with the use of either a standard MP shock (shifting the whole yield curve) or a short-term specific MP shock (shifting only the short end of the yield curve). YCC simulations show the results of YCC programs at different levels of long-term interest rate with an announced duration.
Source: Authors' simulations

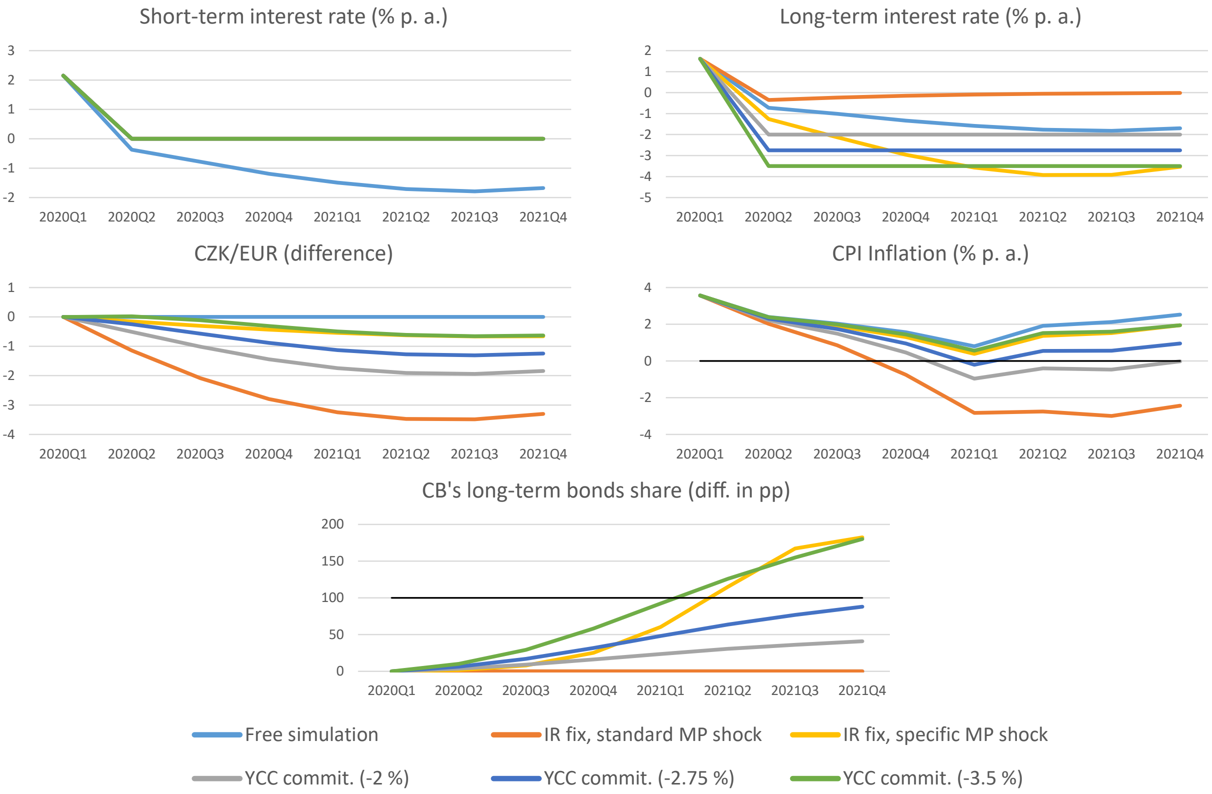
Further, to assess the effects of the choice of level of the effective lower bound, Figure 6 presents the same type of scenario simulation as in Figure 5, while the effective lower bound for the short-term interest rate is set to zero. These results suggest that further easing via a reduction of the ELB for short-term interest rates means that significantly smaller additional easing is needed via long-term interest rates. In this case, it is enough to reduce the long-term interest rates to or slightly below zero. The central bank's cumulative asset purchases would peak at approximately 5 to 10% of the total volume of long-term bonds.

8.2 Pandemic Counterfactual Scenario

The following counterfactual experiments are based on the second pandemic wave scenario, which was published in Inflation Report II/2020, see Czech National Bank (2020). The adverse sensitivity scenario published in the report was in response to an assessment of a resurgence of the pandemic at the early stage of the coronavirus pandemic. Its objective was to evaluate the possible effects of the second pandemic wave expected to materialize during autumn 2020 and winter 2020/2021.

In the early stages of the pandemic, the adverse scenario assumed that the economic slowdown would manifest itself predominantly in demand-side effects.[25] The trajectory of such adverse events without application of the ELB is shown as a free simulation in Figure 7. The short-term interest rate response consistent with the assumptions of this scenario show a deep decline into negative territory. The easing at the short end of yield curve is also supplemented by the long-term easing of monetary policy to well below the ELB. As the ELB is non-binding, no response involving the purchase of long-term bonds by the central bank is needed.

Figure 7: Counterfactual Scenario of Applying a YCC Program in a Pandemic



Note: The free simulation depicts an unrestricted model consistent with monetary easing. IR fix simulations show the effects of a restriction imposed on the short-term interest rate with the use of either a standard MP shock ε_t^M (parallel shift of yield curve) or a short-term specific MP shock ε_t^{MS} (slope shifting at short-term end). YCC simulations show the results of YCC programs at different levels of the long-term interest rate with an announced duration.

Source: Authors' simulations

Further, the presence of an effective lower bound for the short-term interest rate i_t at zero and no long-term bond purchases is assumed in the experimental IR fix scenario (red line). The presence of the ELB is delivered by conditioning on the short-term interest rate trajectory by applying the standard monetary policy shock ε_t^M (parallel shift of the yield curve). Under the ELB assumption for the short-term rate, the long-term interest rate would remain close to zero as well, dipping only slightly into negative territory initially. Such an overly restrictive setting of the monetary policy would result in falling prices and a failure to keep CPI inflation close to its target – the deviation from the free simulation is approximately 5 pp.

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[25] Over the following six months (i.e. two subsequent forecasting rounds), this view was gradually revised towards more supply-side driven effects. Thus, our view was tilting towards a pandemic recession of a stagflationary nature during the period under review. In retrospect, the adverse scenario is viewed as overly pessimistic from the point of view of inflation undershooting the central bank's target.

Alternatively, conditioning on the ELB path for a short-term interest rate i_t using a specific short-term monetary policy shock $\varepsilon_t^M S$ (yellow line) implies a considerably less restrictive impact – the deviation in CPI inflation at the monetary policy horizon with respect to the free simulation is approximately 0.5 pp As the short and long-term interest rate are able to decouple, the additional easing of monetary policy via the long-term interest rate $i_{L,t}$ in line with the unconventional monetary policy rule (i.e. a change in the slope of the yield curve) is delivered. The endogenous trajectory of the long-term interest rate $i_{L,t}$ in this simulation bottoms out at around -4%. This decrease in the long-term interest rate would be accompanied by large central bank interventions at the long-term bond market. Ignoring the higher order effects, the scenario based on a linear model implies that the central bank would have to buy out all the available stock of long-term bonds at the beginning of the second year of the program as shown in Figure 7. Further, an increase in the share of bonds x_t means the exogenous growth of long-term bond supply.

YCC policy may be also applied in the form of a commitment to a long-term interest rate path of $i_{L,t}$. Therefore, the scenario is simulated assuming a commitment of -2%, delivered via a long-term monetary policy shock $\varepsilon_t^M L$, over the forecast horizon (grey line). The trajectories of this scenario show that the commitment applied would lead to a significant improvement in CPI inflation targeting with respect to the ELB restricted case and with no possibility of compensation for long-term interest rates. Under this scenario, consumer prices would still decline slightly but only temporarily. Also, the amount of long-term bond purchases would be moderate – the share of the central bank's long-term bond market would increase by nearly 50 pp.

Further, a more aggressive easing of monetary policy via the long-term interest rate $i_{L,t}$ commitment of -2.75% is examined. Committing to maintaining long-term rates at this level would prevent consumer price deflation. However, this would be at the cost of the central bank buying all outstanding long-term bonds on the market. Thus, this would exhaust any further accommodative potential of bond purchases as an unconventional monetary policy tool.

Finally, in order to deliver similar levels of CPI inflation as in the policy unrestricted free simulation, a long-term interest rate commitment of -3.5% would be necessary. However, as the path for the long-term bond share x_t under this simulation shows, the central bank would have to purchase the complete stock of long-term bonds by the end of the first year of the YCC program.

Two messages can be taken from the results of the pandemic counterfactual scenarios as shown in Figure 7. First, the scenarios expose the possible limitations of the application of the YCC program to the Czech economy. The CNB can only buy the long-term bonds that are already issued and are for sale. After purchasing all the available long-term bonds, portfolio adjustment as an unconventional monetary policy instrument may become ineffective. Therefore, there may be an upper limit on the magnitude of the accommodative effect that can be delivered via the portfolio adjustment costs channel.

Second, considering the paths of the long-term bond share x_t, the limitations of the linear model may be constraining. In the case of extreme long-term bond purchases by the central bank, the volume-price relationship may change. The amount of long-term bonds that the central bank can purchase is limited, but its control of the long-term interest rate might not be. Therefore, at some threshold level of the long-term bond share x_t^*, the central bank may gain significant market power allowing it to set the long-term interest rate $i_{L,t}$ with only a small volume of additional asset purchases. These two messages are complicating making a decisive conclusion about YCC effects in the adverse scenario.

9. Conclusion

In its entire history, the Czech National Bank has never used UMP tools which target the long-term interest rates in practice. However, the CNB applied the exchange rate floor commitment in 2013 when its short-term policy rate hit the ELB and undershot the inflation target amid deflationary fears. Even though an additional monetary easing had been successfully delivered using exchange rate interventions before, a search for alternative UMP options was sparked again during the Covid-19 pandemic in 2020. We describe an alternative UMP approach that is deemed applicable in the Czech circumstances, i.e. YCC. The effectiveness of this UMP tool is supported by reviews such as Reserve Bank of New Zealand (2022b) or Reserve Bank of Australia (2022).

We demonstrate that the presented extension of the core forecasting model as the structural implementation of the YCC regime can be considered simple enough, flexible and easy to use in practice. From the point of view of the forecasting model operators, the actual deployment of such policy change would result in a one-off model change of the core prediction model. The rest of the forecasting toolbox, the set of prognostic tools and procedures, would remain unchanged. From the point of view of the monetary authority, such change would have to be transparently communicated and presented to public. The details of the communication process are beyond the scope of this work, but this paper may constitute an important part of it. Also, the CNB's past experience from the exchange rate commitment period provides important lessons on the communication of policy change.

The setup of the structural extension presented here can be tailored to the characteristics of the YCC program to be deployed in practice.[26] Changes in the YCC program specification can result in the fine tuning of the corresponding model parameters even when such a program is already running in order to provide further guidance to the policymaker. Also, alternative model calibrations can be used for sensitivity scenario simulations at any point. The results suggest that the YCC tool developed here is applicable and operable in practice. Thus, the extended version of the g3+ core prediction model may serve as an additional tool, which can be employed for monetary policy in practice.

Our work aims to support operation readiness for the prospective use of YCC measures in the future. Maintaining high transparency of the CNB's considerations even in the case of various UMP options helps to ensure public and financial market readiness to respond appropriately to the tools, should they be deployed. Similar to lessons learned by Reserve Bank of New Zealand (2022b), such readiness and the documentation of tools is an important pillar of monetary policy authority transparency.

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[26] Moreover, it is also possible to adjust the parameters of the approach described and use it to simulate other types of unconventional monetary policy regimes such as quantitative easing via long-term asset purchases. However, as we argued here, the YCC approach is preferred in the circumstances of the Czech economy.

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Appendix A: Early Approach to UMP Modelling at the CNB

In 2012, the CNB's assessment of its policy stance indicated the need for further policy easing beyond the zero lower bound. One of the concepts under review considered the implementation of policies aimed at reducing long-term interest rates into the CNB's policy framework. The 2013 version of the CNB's core forecasting model, known as the g3 (presented by Andrle et al. (2009)), builds on the assumption that households and firms are able to save and borrow at the short-term interbank rate. Such a simplified assumption may be questionable in the presence of liquidity and risk premiums, as discussed by Shiller and Huston McCulloch (1990). However, arguments by Moore (1988) allow us to abstract from the role of the credit volume and focus on interest rates.

Based on this abstraction, the g3 model was extended to include the role of long-term rates for households and for capital accumulation. The extended version of the core forecasting model includes a monetary policy rate i_t, firms' short-term financing interest rate iF_t and a two-year household loan rate iH_t^{long}. This model extension allows for the introduction of a disconnect between policy rates and long-term rates.

This extension builds on the assumption that firms are unable to borrow at a risk-free rate. Firms have to pay an additional financial markets premium $premF_t^i$ over the monetary policy rate of i_t to reflect firms' specific risk. Financing interest rate for firms of iF_t is introduced and the following interest rate structure emerges:

$$iF_t = i_t \cdot prem_t^{iF}, \tag{A.1}$$

$$prem_t^{iF} = (prem_{t-1}^{iF})^{\rho_{prem^{iF}}} \cdot (prem_{ss}^{iF})^{(1-\rho_{prem^{iF}})} + \varepsilon_t^{prem^{iF}}, \tag{A.2}$$

where $\rho_{prem^{iF}} \in [0,1]$ is premium persistence and $\varepsilon_t^{prem^{iF}} \sim N(0, \sigma^{prem^{iF}})$ is premium driving force. Assuming that this premium is a sunk cost, the interest rate structure implies the following modification of the first order optimality condition of the pricing kernel of households (Equation 3.7 in Andrle et al. (2009)):

$$\frac{1}{iF_t} = E_t\left[\beta \frac{\lambda_t}{\lambda_{t+1}}\right]. \tag{A.3}$$

Further, the economy-wide long-term rate iH_t^{long} is represented by the two-year interest rate for households' loans. Abstracting from the credit volume effects of the presence of long-term bonds, we are able to assume an affine yield curve. This allows us to define the long-term interest rate iH_t^{long} in terms of the expected short-term interest rate i_t and households' loans premium $prem_t^{LR}$ as follows:

$$iH_t^{long} = (i_{t+7} \cdot i_{t+6} \cdot i_{t+5} \cdot i_{t+4} \cdot i_{t+3} \cdot i_{t+2} \cdot i_{t+1} \cdot i_t)^{\frac{1}{8}} \cdot prem_t^{LR}, \tag{A.4}$$

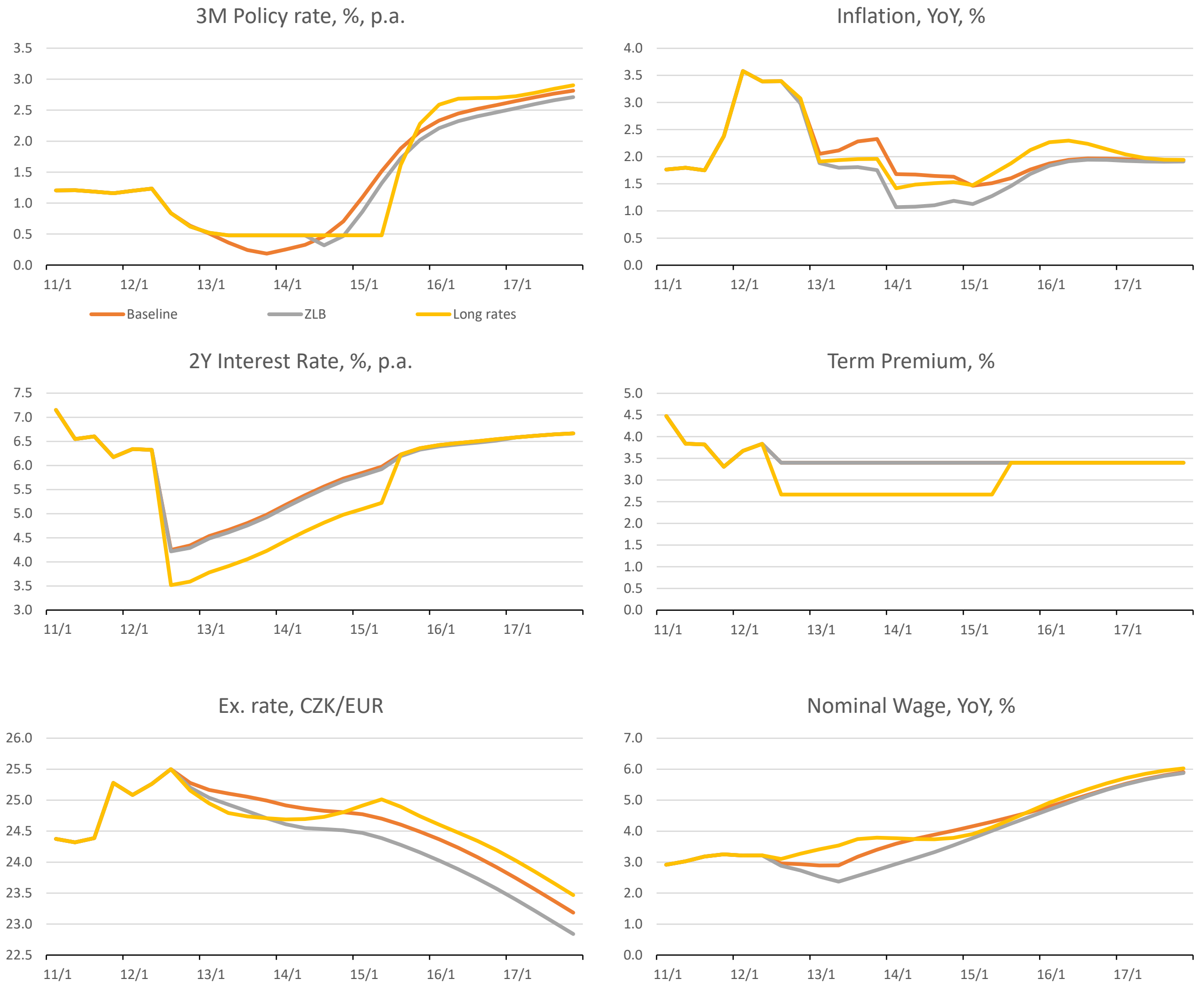
$$prem_t^{LR} = (prem_{t-1}^{LR})^{\rho_{premLR}} \cdot (prem_{ss}^{LR})^{(1-\rho_{premLR})} + eps_t^{premLR}, \tag{A.5}$$

where $\rho_{prem^{LR}} \in [0,1]$ is household long-term financing premium persistence and premium driving force $\varepsilon_t^{prem^{LR}}$, $\varepsilon_t^{prem^{LR}} \sim N(0, \sigma^{prem^{LR}})$.

When fitting the firms' interest rate iF_t to data, the bond premium over the policy rate $prem_t^i$ is derived as the premium between the observed interest rate for firms and the three-month interest rate on the interbank financial market (3M PRIBOR). Similarly, the long-term rate iH_t^{long} is derived from the observation of the household representative rate.

A forward guidance scenario is constructed conditional on the assumption of a number of periods in which the central bank guarantees to keep its policy rate at the given lower bound. When constructing a forward guidance scenario, the core projection model forecast (standard one) was used to identify the number of periods in which the policy rate is below this lower bound.[27] Forward guidance usually includes a commitment to keep rates at this lower bound for an extended period to support further growth away from this lower bound. Therefore, the conditioning on the short-term policy rate trajectory is no surprise to economic agents (anticipated information). Figure A1 summarizes the results of the CNB's forward guidance policy experiment. Here, the lower bound for the 3M rate was assumed to be at 0.5% p.a. The baseline (red line) simulation without a restriction on the policy rate level shows that the implied response is below the set level for seven periods. Our zero lower bound policy experiment (ZLB, grey line) reveals that the ZLB commitment itself will be contractionary and result in a 1 pp deviation from the inflation target in 2014.

Figure A1: Policy Experiment: Long-Term Rates



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[27] The view on the level of the lower bound has changed over the course of the past decade. The CNB adopted the term "technical zero" in 2012 when its two-week policy rate was cut to 0.05% p.a., as presented in Czech National Bank (2012).

Therefore, a necessary part of the forward guidance design is the promise to suppress long-term rates to offset the contractionary effect not delivered over these seven periods by undercutting the given zero lower bound. Additionally, we assumed that the 3M rate should remain at the zero lower bound until the second quarter of 2015 (yellow line) to allow a smooth phasing out from the long-term commitment.

This simulation of a forward guidance experiment shows that such a policy can offset the contractionary effects of keeping the short-term policy rate at the given lower bound. In addition, this model extension provides scope for the experiments, with forward guidance commitment parameters which include the length of the commitments and the extent of the long-term rate interventions. Therefore, policymakers can identify the effects of their forward guidance settings and fine tune its parameters.

We view forward guidance as a monetary policy tool as it allows central banks to provide information about the likely future course of monetary policy and the state of the economy. As such, forward guidance can take various forms including announcements about the bank's objectives, contingencies, policy actions and speeches.[28]

An indication, or even commitment, by the central bank that it will keep its short-term rate lower for longer than previously expected usually triggers a positive effect on inflation expectations and economic activity. This form of forward guidance can effectively support future economic growth.

In order to inject more cash into the system, the ECB, the Fed and the BoE bought massive amounts of government bonds or other investments from banks.[29] This motivation led to the dominance of the volume effect of quantitative easing over the price effect. Therefore, the general feature of the forward guidance policies applied in the aftermath of the 2008 financial crisis is that they resulted in a reduction in nominal medium to long-term interest rates.

However, given that the Czech banking sector operated in conditions of excess liquidity, the CNB's primary focus was not pouring money into banks. The CNB aimed rather to reduce long-term interest rates (price effect) in a situation of a binding lower bound constraint for short-term interest rates. The idea that central banks can control the long-term interest rates was present even before the outbreak of the 2008 financial crisis. Moore (1988) has already argued that the supply of credit money is endogenous, demand-determined, and thus only its price, and not its quantity, can be controlled by the central bank. Thus, the forward guidance effects can be via effects on the short-term policy interest rate and the long-term interest rates on public and private bonds.

Also, present literature widely documents that forward guidance can produce extremely large impulse responses (e.g. Carlstrom et al. (2015)) in model simulations. The experience of the CNB shows that careful consideration about conditioning the duration of the announced policy rate on the future state of the economy can avoid extreme and unrealistic outcomes. One key element is the role of the announcement, as Graeve et al. (2014) document the presence of significant distortions as the implication of imperfectly informed agents who face forward guidance policies.

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[28] On its path towards high transparency, the CNB started to publish the endogenous interest rate path consistent with its forecast in early 2008. Later, in 2008, it also added the exchange rate path in its communication of the forecast. Thus, the CNB, as a transparent inflation-targeting bank, had already been using forward guidance as an implicit instrument when the 2012 slowdown of the real economy began.

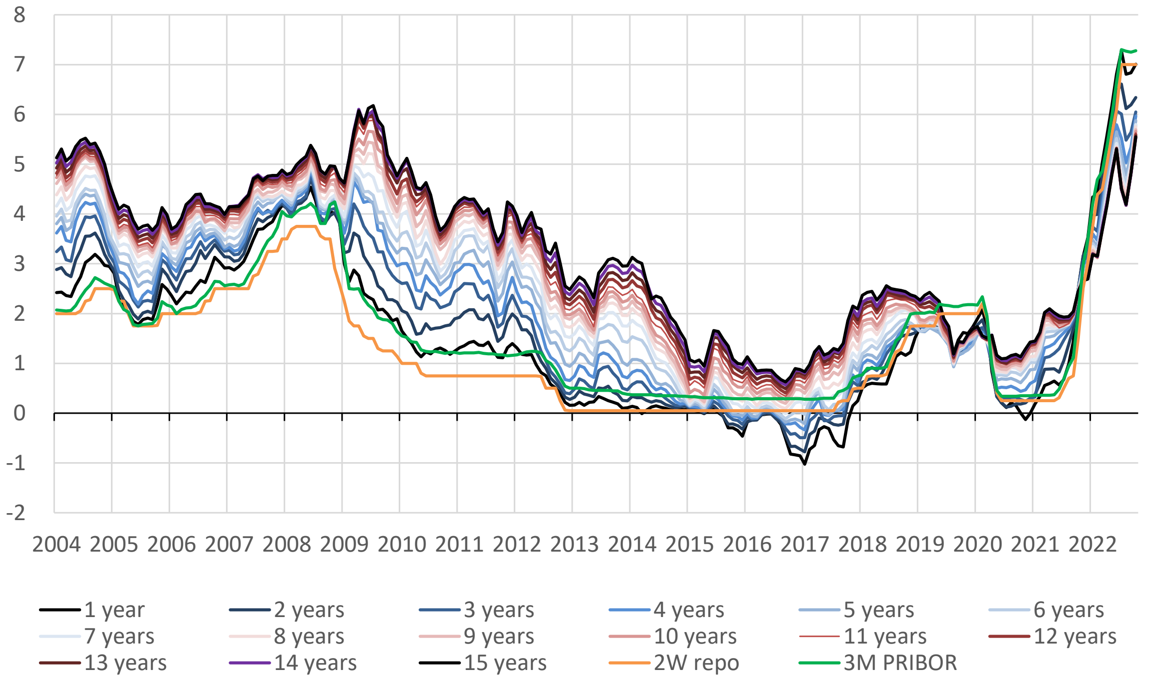
[29] For more details, see Cour-Thimann and Winkler (2013).

Appendix B: Czech Government Bond Yield Curve Characteristics

In this section, we provide further details on the history of Czech sovereign interest rates. In general, we track the evolution of short-term interest rates on the interbank market (the CNB's 2W repo rate and 3M PRIBOR) as well as the long-term interest rates related to Czech government bonds, i.e. the bond yields at different residual maturities.

Figure B1 shows the history of Czech government bond yields at different residual maturities (in years). The differences between the residual maturities presented here allow us to define the bond term premium, known as the yield premium[30]. This term premium reflects the expectations about future change in the riskiness and demand–supply relationship by asset (bond) buyers. Much of the history of Czech government bond yields is characterized by a somewhat steep yield curve at its short end while its slope gradually declines as the residual maturities of underlying bonds gets longer. Over this period, we observe a large premium for each additional year of residual maturity for short-term bonds. As the maturity of underlying bonds gets longer, the premium declines. Following our definition of this means that the extent of expected change is larger in the near future (1 and 2 years), while it declines as the maturity is extended.

Figure B1: Czech Government Bond Yields - Residual Maturity (%, p.a.)



Source: CNB, ARAD database

Figure B2 compares the domestic government bond yield curve at the beginning of each year. In the period of economic boom before the Global Financial Crisis of 2008, the average government bond yield curves were at elevated levels (around 4%, see Figure B3) and had a gradually decreasing positive slope. This shape was supported by a tightening of the CNB's monetary policy in response to increasing inflation pressures from the domestic economy. As the CNB sets its short-term rates

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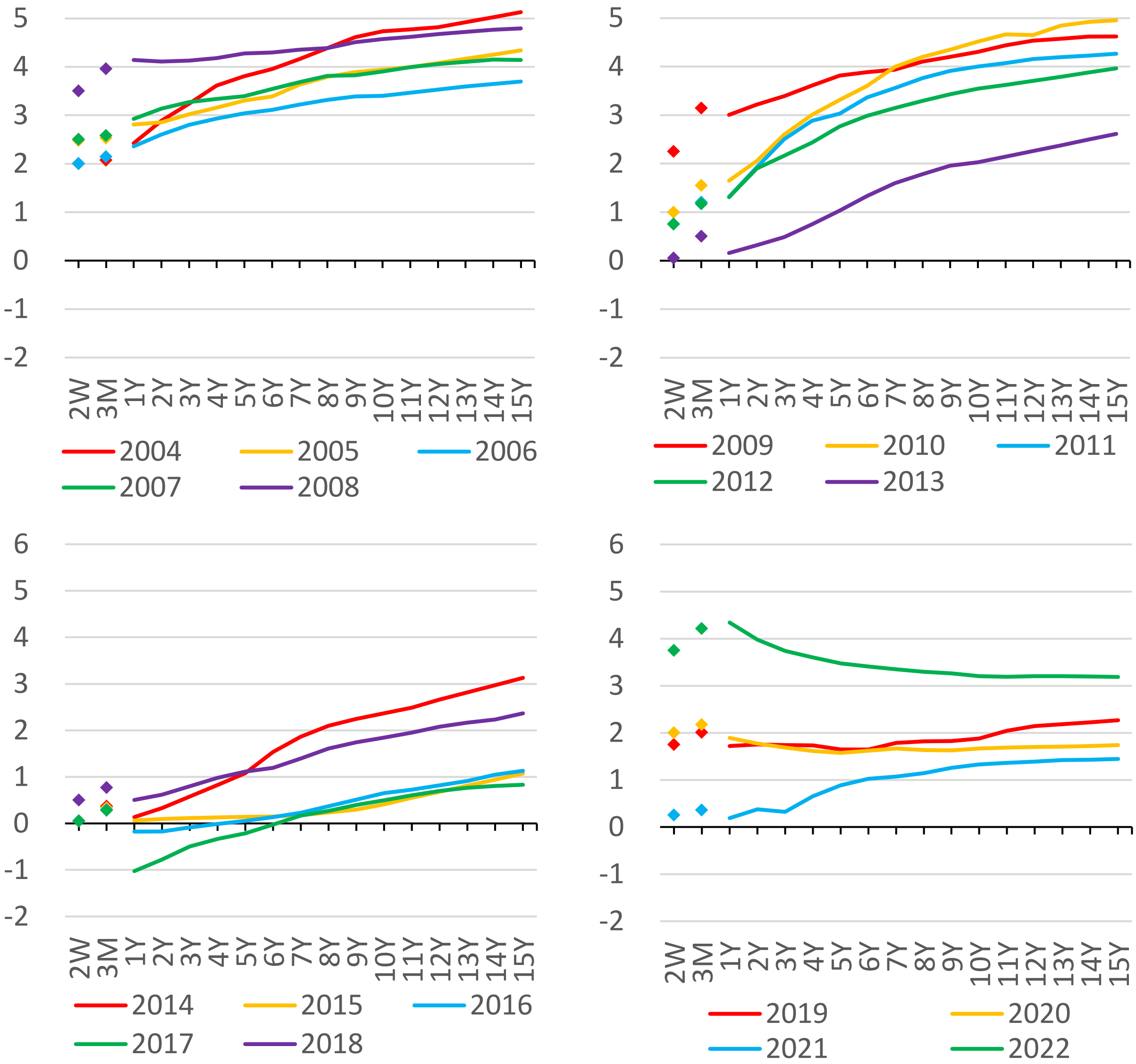
[30] The bond buyers usually demand additional compensation in terms of bond yields for a longer duration of time, before the bondholder gets paid back the face value at maturity due to the risks of holding a long bond.

(two-week repo rate) directly, which is quickly transmitted into the short-term interbank interest rate (three-month PRIBOR rate), the short end of the yield curve responds strongly. After the

Figure B2: Czech Government Bond Yield Curve (%, p.a.)

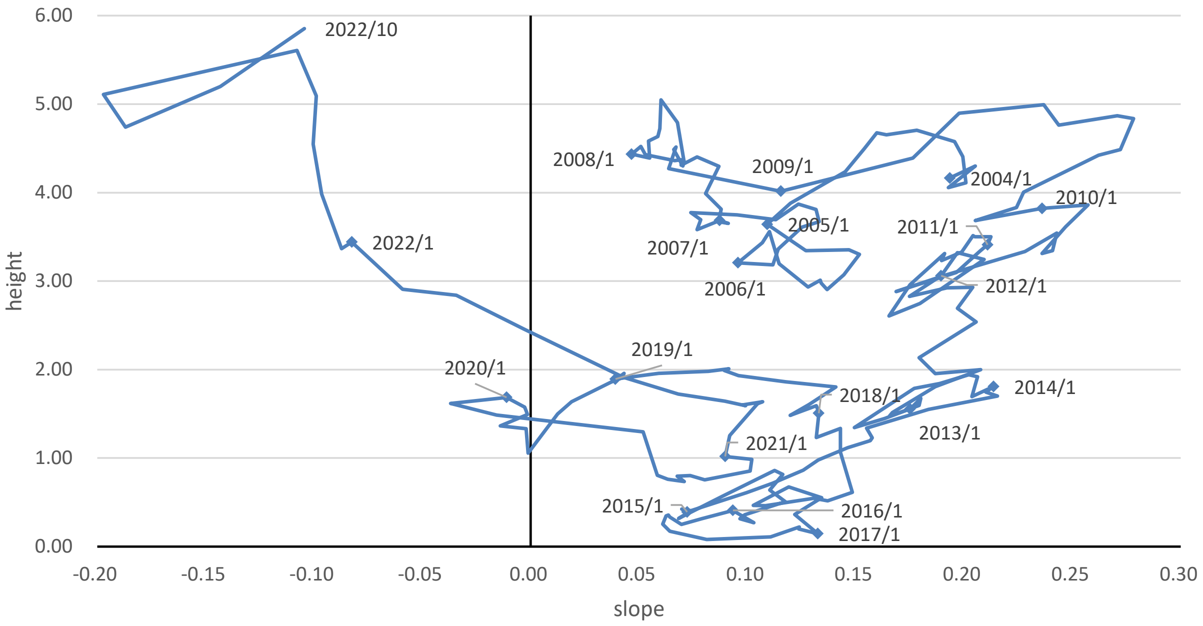


Note: The graphs show the yield curve in January of a given year. 2W stands for two-week repo rate; 3M represents the three-month PRIBOR interbank lending rate.

Source: CNB, ARAD database

Global Financial Crisis hit the domestic economy in late 2008 and 2009, the Czech National Bank eased its monetary policy. This drove government bond yields down – especially on the shorter maturities – as the yields on longer maturities account for future high inflation risk expectations. Thus, the slope of the yield curve increased even further. Subsequently, in 2010, the resolution of the EU debt crisis and the launch of asset purchases by the ECB (QE) drove domestic policy rates downwards. Domestic rates reached "technical zero" (the effective lower bound) within three years. In this period, the global low interest rate environment (referred to at the time as the "new normal") gradually affected the yield curve over all maturities and the average government bond yield fell to below 2% in 2013.

Figure B3: Czech Government Bond Yield Curve – Average Level and Slope (%, p.a.)



Note: The level of the yield curve is calculated as an average over all considered maturities. The slope of the yield curve represents the average annual time premium.
Source: CNB, ARAD database

A low global interest rate environment, a relentless low inflation economic environment and the need to avoid deflation motivated the CNB to use a foreign exchange rate commitment as an additional monetary policy tool. The CNB commitment to maintaining the exchange rate of the koruna to the euro at 27 CZK/EUR or weaker stretched over the period between November 2013 and April 2017. In response, the short end of the yield curve even dipped into negative territory in 2016 and 2017. After domestic economic activity started to become more robust, the foreign exchange rate commitment was discontinued and domestic policy rates started to increase gradually.

However, the medium- to long-term yields remained under pressure from the globally low interest rate environment long after the end of the exchange rate commitment. The yields on medium-term government bonds stayed well below 2% in 2019–2020. Thus, as in 2008, the short end of the yield curve reacted to the upward shift in domestic monetary policy and the slope of the yield curve declined further, eventually leading to an inverted yield curve[31] in this period.

The unprecedented fast decline in domestic policy rates in response to the global pandemic drove the short end of the yield curve down, resulting in the restoration of a positive slope of the yield curve as a whole. The strong economic activity rebound in 2021 was accompanied by a steep rise in inflationary pressures driven by pent-up demand as well as disrupted global value chains. The CNB promptly recognized the coming inflationary wave and its decisive restrictive policy response has thus driven the whole yield curve into higher territory once again. This restrictive monetary policy stance was publicly communicated and perceived as temporary with an outlook of gradually

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[31] An inverted yield curve occurs when short-term interest rates exceed long-term rates. Under normal circumstances, the yield curve is not inverted since debt with long maturities typically carry higher interest rates than nearer-term ones.

normalizing (i.e. decreasing) policy rates towards the long-term average. Thus, the slope of the yield curve turned negative once again at the end of 2021.

In early 2023, the risk that the CNB's monetary policy will be under pressure from the binding zero lower bound for its main monetary policy instrument – the short-term interest rate – is low. However, history suggests that this type of event is feasible. This situation already occurred in 2013 when the CNB dealt with it by using the exchange rate as an alternative monetary policy instrument. Given this possibility, we are constantly investigating UMP tool options, in particular YCC, which may be of use if the zero lower bound is a binding constraint.

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