THEMATIC ARTICLE ON FINANCIAL STABILITY

Adam Kučera, Milan Szabo

ESTIMATING THE NEUTRAL CZECH GOVERNMENT BOND YIELD CURVE

3 / 2019

CZECH NATIONAL BANK

The thematic articles on financial stability respond to selected topical financial stability-related issues. They are aimed at disseminating the results of financial stability analyses and specific aspects of macroprudential policy in an educational and easy-to-understand form. They constitute a stand-alone series of publications supporting the analyses and conclusions of Financial Stability Reports.

The opinions contained in this article are those of the authors and do not necessarily reflect the official position of the Czech National Bank.

Editor: Zlatuše Komárková

Coordinator: Simona Malovaná

Issued by: Czech National Bank
Financial Stability Department
Na Příkopě 28, 115 03 Prague 1
Czech Republic

Contact: Communications Division, General Secretariat
Tel.: +420 22441 3112
Fax.: +420 22441 2179
http://www.cnb.cz

ESTIMATING THE NEUTRAL CZECH GOVERNMENT BOND YIELD CURVE

Adam Kučera, Milan Szabo[1]

This article presents the neutral Czech government bond yield curve and the method used to construct it. The neutral yield curve shows the Czech government bond yields at which the economy is in equilibrium, inflation is at the target, risk premia are at their long-term average levels and investors do not expect any future deviation from this state. The method presented in this article allows us to identify the factors responsible for the deviation of market yields from neutral yields. By applying the method to data for the period 2003–2018, we show that the Czech government bond yield curve has been well below its neutral level since 2009. At the start of the period under review, this deviation was caused mainly by a negative cycle in real rates due to accommodative monetary policy. In the period that followed, higher demand for Czech government bonds – caused mainly by unconventional monetary policy instruments – contributed to the deviation. At the end of the period under review, a low term risk premium was the main cause of the persisting deviation.

1. INTRODUCTION

Yields on Czech government bonds (GBs) contain a wealth of important information. The yield – which is inversely related to the price – allows us to assess how high or low bond prices are in historical terms. Knowledge of GB yields across various maturities (i.e. the yield curve) also provides information not only on the present price of money, as reflected in short-maturity GB yields, but also on the expected future price of money, affected by expectations about future monetary policy, and risk appetite. All this information – expectations about the price of money, risk assessments and the degree to which prices are over/undervalued – is crucial for assessing short- and long-term risks in the Czech financial system. The CNB therefore uses methods to identify the components of Czech GB yields and to explain yields in the context of those components (Kučera et al., 2017).

This article presents a new method for estimating the neutral GB yield curve, namely the level of yields on GBs of various maturities at which the key components influencing those yields are in balance and investors do not expect them to change in the future. This means that the present and expected real short-term interest rate is at its natural level, inflation is at the target and risk premia are at their long-term average levels. The neutral yield curve is thus an extension of the concept of the natural rate of interest (see Laubach and Williams, 2003, and, for the Czech Republic, Hlédik and Vlček, 2018).[2] The natural rate of interest is the real short-term rate at which monetary policy is neither restrictive nor expansionary. In other words, it is *neutral with respect to the economic cycle and inflation pressures*. Besides the natural rate of interest, neutral yields contain a nominal component. It comprises the inflation target, representing the neutral value of expected inflation. The natural rate of interest concept is further extended to include a component consisting of neutral risk premia, which are derived from long-term average GB yields. Incorporating these additional components allows us to

1 Adam Kučera (Adam.Kucera@cnb.cz), Milan Szabo (Milan.Szabo@cnb.cz), both CNB, Financial Stability Department.
2 Brzoza-Brzezina and Kotlowski (2012) previously proposed an extension of the natural rate of interest concept (Laubach and Williams, 2003) in the form of a natural yield curve. They describe the yield curve using three factors based on Nelson and Siegel (1987) – level, slope and curvature – and estimate the natural value of each. In order to identify the model, they also assume that (i) the level always equals its natural value and (ii) the curvature is constant. These restrictions mean that all the volatility of the yield curve around its natural value is governed by its short end. The natural yield curve identified in this way can be a useful monetary policy tool. However, it does not include risk premia, so it does not offer a broader view of the macro-financial environment.

draw up an entire time structure of neutral yields – a neutral yield curve. The neutral yield curve is thus a broader concept than the natural rate of interest, offering *values neutral with respect to the macro-financial environment*. Knowledge of the neutral yield curve allows us to assess the past dynamics of GB yields, distinguishing between cycle and trend effects. The degree of deviation of yields and their components from their neutral values indicates the possible path of future yields in the event of a return to neutral values. The neutral yield curve is therefore a suitable tool for assessing the severity of certain risks to financial stability arising from the macroeconomic conditions (such as a low-yield environment) and from developments in financial markets (such as interest rate risk and the risk of contagion via fire sales of GBs).

The following section presents the method used by the CNB to construct the neutral GB yield curve. Section 3 gives an estimate of the neutral Czech GB yield curve. Section 4 offers a detailed discussion of the deviation of the market Czech GB yield curve from the neutral yield curve calculated using the method presented, and identifies the implications for the overvaluation of Czech GB prices. The final section concludes.

2. THE METHOD USED BY THE CNB TO CONSTRUCT THE NEUTRAL YIELD CURVE

The method is based on identifying the components contained in Czech GB yields. The basic motivation and the identification of the components are in line with Kučera et al. (2017). Yields can be divided into a risk-neutral (or risk-free) yield, which reflects the present price of money (the monetary policy rate) and expectations about its future evolution, and a risk premium (see Table 1). The risk-neutral yield can be decomposed into a real interest rate component and a nominal component reflecting expected inflation. The risk premium is made up of three components: term risk premium (linked with the uncertainty about the future price of money), credit risk premium (issuer default risk) and portfolio risk premium (or liquidity, reflecting specific demand effects). A neutral (i.e. equilibrium) value and a cyclical value are distinguished for each of the components. The neutral yield curve is the sum of the neutral values of the components of the yield.

TABLE 1

Neutral yield curve construction framework

Components of the yield		**Market variables**			**Calculation**	
		GB yield	IRS rate	CDS rate	Neutral value	Cyclical value
Risk-neutral yield	Real interest rate	•	•		(a) Taken from Hlédik and Vlček (2018) (b) Estimated from BaR	Estimated from BaR
	Inflation component of yields	•	•		Constant: CNB's 2% inflation target	Estimated from BaR
Risk premium	Term RP	•	•		Estimated from BaR (*)	
	Credit RP	•		•	Estimated from factor decomposition of CDS rates (*)	
	Portfolio (liquidity) RP	•			Difference between GB yield and IRS rate net of credit RP (*)	

Source: Authors
Note: (*) The neutral and cyclical values for the risk premia are differentiated by filtration.
IRS = interest rate swap, CDS = credit default swap, GB = government bond, RP = risk premium, BaR = Bauer and Rudebusch (2017).

The estimation of the neutral and cyclical values of the components draws on the fact that Czech GB yields are correlated with koruna interest rate swap (IRS) rates.[3] Unlike GB yields, though, IRS rates contain negligible credit and portfolio risk premia, as IRS do not involve any exchange of the nominal value of the instrument, and IRS are more difficult to use to allocate part of a portfolio, including speculative trades. The IRS rate thus corresponds broadly to the first three components of the GB yield (the light grey area of Table 1). These components and their neutral and cyclical values are estimated on the basis of IRS data using an affine interest rate model, which is a consistent approach to estimating interest rates under no-arbitrage conditions.[4] The GB credit risk premium and its neutral value are modelled separately using factor decomposition of the credit default swap (CDS) rate. The last remaining component – the portfolio risk premium – is the residual in GB yields.

2.1. The affine model

The affine interest rate model used to estimate the first three components and their neutral values is based on the model of Bauer and Rudebusch (2017, henceforth BaR). This is a factor model in which yields $y_t(\tau)$ are an affine function of factors $r_t^*, r_t^c, \pi_t^*, \pi_t^c, f_t$, time to maturity τ and parameters $\phi_r, \phi_\pi, A(\tau), B(\tau)$:

$$y_t(\tau) = r_t^* + \frac{1-\phi_r^\tau}{\tau(1-\phi_r)} r_t^c + \pi_t^* + \frac{1-\phi_\pi^\tau}{\tau(1-\phi_\pi)} \pi_t^c + A(\tau) + B(\tau) f_t \quad (1)$$

Factors r_t^* and r_t^c jointly determine the real interest rate (the first component of yields). r_t^* is a non-stationary factor representing the natural rate of interest (i.e. the neutral value) and has the same weight in yields of all maturities. The non-stationarity assumption allows us to capture long-term trends in yields. r_t^c is a stationary factor representing the cycle allowing the actual real interest rate to fluctuate around r_t^*. As we assume gradually closing cyclicality at longer maturities, the weight of this factor $(1-\phi_r^\tau)/(\tau(1-\phi_r))$ is greatest for yields on bonds with a short time to maturity. Therefore, the weight of the current cycle in the real interest rate decreases with increasing time to maturity.[5] The inflation (second) component of nominal yields is specified analogously, with π_t^* representing the non-stationary trend (neutral) value of expected inflation and the value of π_t^c controlling the stationary cyclical volatility in expected inflation. Likewise, for inflation, the neutral value is fully contained in the yields on bonds of all maturities, while the cyclical part is strongest for short maturities.

The term risk premium (the third component of yields) is controlled by $A(\tau)$ and $B(\tau)$ and by the evolution of f_t. This factor can be seen as close to the degree of risk aversion. $A(\tau)$ and $B(\tau)$ are functions of maturity τ and are derived on the basis of the no-arbitrage condition (see BaR

3 The coefficient of correlation between the ten-year koruna IRS rate and the ten-year Czech GB yield in 2003–2018 is 94% based on the month-end figures and 68% based on the monthly changes in yields. Kučera et al. (2017) offer a detailed discussion of this relationship.

4 Affine models are a broad set of interest rate factor models based on Duffie and Kan (1996) characterised by (1) linearity and (2) the no-arbitrage condition. They are widely used in the academic literature and by central banks to differentiate between the risk-neutral component and the risk premium of GB yields. For US government bonds, see, for example, the estimate of the *FRB of New York* and the estimate of the *FRB of San Francisco*.

5 This is because the risk-neutral yield reflects the expected average price of money (the monetary policy rate) at the bond maturity horizon. For short maturities, this average expectation is strongly affected by the current monetary policy rate, because the cyclical deviation is not expected to close fully in the short term. For longer maturities, the part of the expectation for which the deviation will have mostly closed in the future predominates. The actual speed of closure of the cyclical deviation is controlled by the value of ϕ_r, which is estimated in the model.

for more details).[6] The term risk premium increases with time to maturity and forms a counterweight to the diminishing significance of cyclical factors r_t^c and π_t^c at the longer end of the yield curve. Risk factor f_t is not explicitly decomposed into neutral and cyclical parts in the BaR model. We therefore use the ten-year moving average of this factor to obtain the neutral value of the term risk premium.[7] The cyclical value is the difference from this average. The long-term average allows us to capture long-term trends in risk perceptions in financial markets and also to smooth the macroeconomic and financial cycles.

The path of the non-stationary factors r_t^* and π_t^* can be expressed as a random walk, while that of the factors r_t^c, π_t^c and f_t can be described by the stationary autoregressive process:

$$r_t^* = r_{t-1}^* + \varepsilon_{1t};\quad \pi_t^* = \pi_{t-1}^* + \varepsilon_{2t};\quad r_t^c = \phi_r r_{t-1}^c + \varepsilon_{3t};\quad \pi_t^c = \phi_\pi \pi_{t-1}^c + \varepsilon_{4t};\quad f_t = \phi_f f_{t-1} + \varepsilon_{5t} \qquad (2)$$

where $\varepsilon_{1\ldots5t}$ are normally distributed random shocks to the factors. Combining equations (1) and (2) gives us the affine model in state-space form. Moreover, it is assumed in the model that π_t^* equals the CNB's inflation target. The model specified in this way is estimated in two variants. In the first, the value of r_t^* is treated as observed and the estimate of the natural rate of interest given in Hlédik and Vlček (2018) is used for it. The remaining factors r_t^c, π_t^c and f_t are estimated using the Kalman filter. The values of the model parameters in equations (1) and (2) are estimated using the maximum likelihood method. In the second variant, r_t^* is treated as unobserved and the model is estimated using Bayesian techniques. Initial assumptions are made regarding the variance of the factors. It is also assumed that r_t^c partially copies the output gap. All these assumptions determine the prior distribution of the model parameters in equations (1) and (2). The final (posterior) distribution of the model parameters is obtained by means of the Metropolis-Hastings algorithm.[8]

2.2. Factor decomposition of the CDS rate

The remaining yield components are the credit and portfolio risk premia. These components jointly represent the difference between observed Czech GB yields and koruna IRS rates. In this section of the article, we present a method that explicitly models the credit premium. The portfolio component is then implicitly derived as the residual.

The credit premium for small economies is characterised by an abrupt switch between a relatively low and relatively high level. This property is also observed for quoted CDS rates for Czech GBs, which, given their linkage to credit risk, are used here to estimate GB credit risk premia. To estimate the neutral and cyclical credit risk premia, we decompose the CDS rates into a combination of linear and non-linear components (equation 3). The linear component reflects neutral pricing of credit risk and is obtained as a linear combination of factors f_1, f_2, f_3 presented below. The non-linear component captures the significant growth in CDS rates seen at times of market uncertainty. We assume it depends on the same factors f_1, f_2, f_3.

6 The derivation of these parameters is relatively complex and is beyond the scope of this article.
7 The application of a longer/shorter moving average was also tested for the estimation of the neutral term risk premium. This resulted in slightly lower/higher volatility of the neutral yields. However, the general results and conclusions of the analysis presented below were not significantly affected by the window length used to calculate the average.
8 The priors for the parameters are set similarly as in Bauer and Rudebusch (2019).

Nonlinearity is achieved by means of the risk spread implied from the Merton credit model, which is adjusted for the calculation of central government credit risk.[9]

$$CDS\ rate\ =\ \text{linear\_component}(f_1, f_2, f_3) + \text{nonlinear\_component}(f_1, f_2, f_3) \qquad (3)$$

The choice of factors entering the two components is guided by the need to capture the information the market can reflect in the pricing of the sovereign credit risk premium and hence in CDS rates. The first factor f_1 contains information on the fiscal soundness of central government. It is expressed as an indicator (BudgetRisk) that compares budget revenues with mandatory expenditures. While the first factor represents a fundamental source of risk in the form of the budget situation of central government, the second and third factors aim to capture the effect of market uncertainty, which may not be grounded in fundamentals only. This is motivated, for example, by the evolution of Czech GB yields and CDS rates in the wake of the European debt crisis, when the assessment of Czech sovereign credit risk was strongly affected by that of risk in neighbouring countries (see, for example, Frait, 2019). We use the sovCISS indicator (see Garcia-de-Andoain and Kremer, 2018) to capture the link between uncertainty on the GB market and the pricing of its credit premium, i.e. the CDS rate. We include two calculations of the indicator, the first for the Czech Republic ($SovCiss_{CR}$, or f_2) and the second for the euro area ($SovCiss_{EMU}$, or f_3). The inclusion of f_3 allows us to capture the spillover of rising credit premia and negative sentiment from other countries to the Czech Republic.

After substituting these factors into equation (3) for f_1, f_2, f_3 and separating the linear and non-linear functional relations between the factors and the CDS rate, we can write equation (4) as:

$$CDS\ rate = \alpha_{budget} \cdot BudgetRisk + \alpha_{sovCISS_{CR}} \cdot SovCiss_{CR} + \alpha_{sovCISS_{EMU}} \cdot SovCiss_{EMU} + \beta \cdot Merton_{CDS}(w_{BudgetRisk}, w_{sovCISS_{CR}}, w_{sovCISS_{EMU}}, BudgetRisk, SovCiss_{CR}, SovCiss_{EMU}) \qquad (4)$$

where $\alpha_{budget}, \alpha_{sovCISS_{CR}}, \alpha_{sovCISS_{EMU}}, \beta, w_{budget}, w_{sovCISS_{CR}}, w_{sovCISS_{EMU}}$ are parameters of the model. They are estimated numerically by minimization of the deviations between the CDS rates explained by the model and those quoted on the market for the various maturities.

The model estimated in this way allows us to obtain the neutral level of the credit risk premium in the GB yield curve. It is calculated only from the linear component of CDS rates, while the part of CDS rates explained by non-linear developments is regarded as the cyclical value of the credit premium. After estimation, the linear component is smoothed using the ten-year moving average, with the same motivation as that for the term risk premium (see above).

The residual portfolio component of yields is the sum of all other effects. As with the preceding risk premia, we smooth the neutral value of the portfolio risk premium using the ten-year moving average.

9 The Merton credit model has been applied to estimate sovereign credit risk by, for example, Gapen, Gray, Xiao and Lim (2005). Credit risk is captured by a decline in the market value of assets to the “distress barrier” or by an increase in asset volatility. The market value of assets is estimated in the model using option pricing equations (Black and Scholes, 1973). To apply this model to Czech sovereign credit risk, we opted for a modification that links the non-linear credit premium to the same factors as the linear component. This makes it easier to estimate the model and interpret its results.

3. NEUTRAL CZECH GOVERNMENT BOND YIELDS

We used monthly koruna IRS rates and GB yields (month-end data) in 7/2003–12/2018 to estimate the neutral Czech GB yield curve. From these data, we drew up zero-coupon yield curves for maturities of 1–15 years using the Fama-Bliss method (Fama and Bliss, 1987), which assumes a constant forward rate between two data points. To calculate the credit premium, we used CDS quotations for Czech GBs, data on the state budget (CNB, 2019c), data on total central government debt (MF CR, 2019) and the sovCISS index time series (ECB, 2019). The inflation target, which is an observed value π_t^*, was set at 2% for both variants over the entire period. The estimate of the natural rate of interest r_t^* for the Czech Republic given in Hlédik and Vlček (2018) was used as the data input for the first variant of the estimation of the interest model. In the second variant, the estimate of the output gap given in OECD (2019) was used instead. The time series of the CNB's monetary policy two-week repo rate (CNB, 2019a), historical inflation (CZSO, 2019) and inflation expected one year ahead obtained from financial market inflation expectations surveys (CNB, 2019b) were also incorporated into the estimation of the state-space model as additional observed variables refining the identification of the model.[10]

Charts 1 and 2 compare the observed yield with the neutral values estimated in the two variants of the model. For one-year maturity, the neutral yield is steadily falling in the case of the estimate of the natural rate of interest in the model, whereas the estimate using data from Hlédik and Vlček (2018) fluctuates in the range of 2%–5%. This is because the estimate in Hlédik and Vlček (2018) uses purely macroeconomic data, whereas that in the model combines macroeconomic and market data. The neutral yield and the natural rate of interest estimated in the model are thus more consistent with the price of money perceived by investors, while the figures based on the natural rate of interest from Hlédik and Vlček (2018) are consistent with macroeconomic developments. For the ten-year yield, a decline in neutral yields is apparent for both variants. This is due to the greater significance of neutral risk premia at higher maturities. The neutral risk premia are falling in the period under review.

The last time market yields were close to their neutral values was at the end of 2008. The subsequent decline in monetary policy rates and the onset of a low-yield environment kept Czech GB yields several percentage points below their neutral values. This gap in yields was still apparent at the end of 2018, despite having closed partially by comparison with its absolute peak in 2015–2016. According to the estimate, the gap was -94 bp and -233 bp for one-year and ten-year Czech GBs respectively at the end of 2018.[11]

The results also offer an explanation of the downward trend in long-term Czech GB yields observed over the last 15 years. This trend reflects a similar trend in GB yields abroad (see the discussion in BaR). Our method, based on the BaR model, thus allows us to explain how much this trend is cyclical and how much it represents a genuine structural shift. The results indicate that for the ten-year Czech GB the decline was caused by both factors. In the period under review, the neutral yield fell by 2.15 pp and the cycle contributed to market yields moving further away from their neutral values. The fact that long-term yields stayed below their

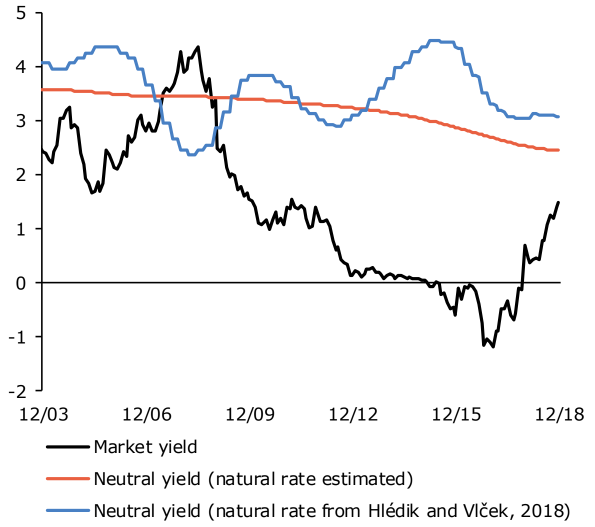
10 Some of the data were not available for the entire period or were available at lower-than-monthly frequency (the output gap estimate and the natural rate of interest). However, this did not hinder the estimation of the model, as the state-space representation of the model and subsequent factor filtration allow us to supplement the missing data with estimates in the model.
11 Or -158 bp and -292 bp respectively for the estimate using the observed natural rate of interest from Hlédik and Vlček (2018).

neutral value over the entire period under review is linked with this. The continuous decline in risk premia fed through relatively slowly to the neutral risk premium, which thus remained above the actual risk premium for the entire period. If a moving average with a shorter window was used to calculate the neutral risk premium, the neutral long-term yield would copy the market yield more closely, but a similar downward trend would still be evident.

CHART 1

Neutral and observed one-year Czech GB yields

(%)

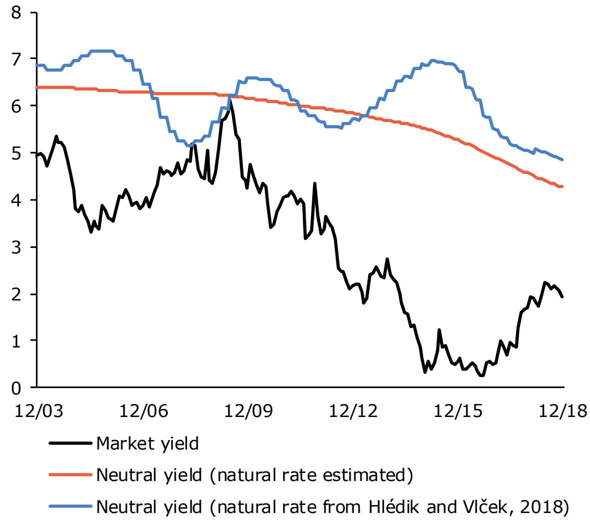


Source: CNB, Bloomberg, Prague Stock Exchange, MTS Czech Republic, Thomson Reuters, authors' calculations

CHART 2

Neutral and observed ten-year Czech GB yields

(%)



Source: CNB, Bloomberg, Prague Stock Exchange, MTS Czech Republic, Thomson Reuters, authors' calculations

4. OVERVALUATION OF CZECH GOVERNMENT BOND PRICES

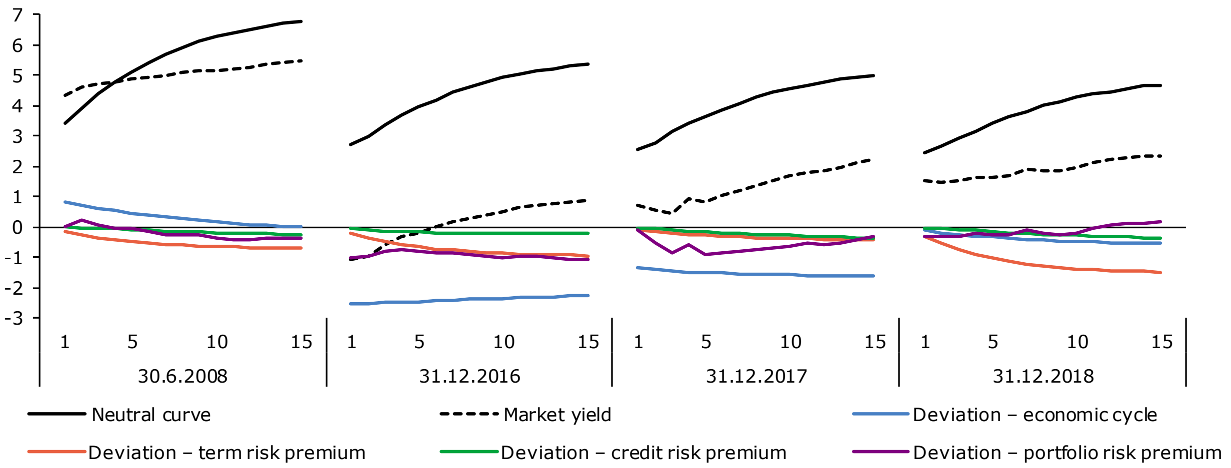
The cause of the deviation of market yields from neutral yields is key to assessing the risks associated with the relationship between them. The deviation in the real rate or inflation expectations is linked with the macroeconomic situation and can thus indicate risks more of a long-term nature (such as the risk of yields staying at a low level for a long time). By contrast, the cyclicality in risk premia is closely linked with financial market sentiment, and the ensuing risks can materialise in a few days. If market uncertainty arises, a low risk premium can be revised sharply towards its historical average, or even briefly above it. This can lead to relatively large falls in bond prices.

Chart 3 shows the history of the neutral yield curve and the related deviations. In mid-2008, the market government yield curve and the neutral curve intersected because of restrictive monetary policy. The deviation of the macroeconomic components (the cyclical component of the real interest rate and inflation expectations) was positive for the shortest yields and gradually diminished to zero for 15-year maturity. This reflected investors' expectations that monetary policy rates would stay elevated for only a short time and return to equilibrium in the longer term. On the other hand, the low risk premia helped keep the long end of the yield curve below its neutral value.

CHART 3

The neutral yield curve and analysis of deviations

(%, deviations in pp)



Source: CNB, Bloomberg, Prague Stock Exchange, MTS Czech Republic, Thomson Reuters, authors' calculations.
Note: The deviation of the economic cycle contains the real interest rate cycle and the inflation expectations cycle. The neutral curve and the deviation are calculated from the second variant of the interest model, where the natural rate of interest is estimated. If the first variant were used, the absolute deviation of the real interest rate in 2016–2018 would be larger (i.e. it would be more distant from the neutral curve).

Following an economic contraction in 2009 and subsequent monetary policy expansion, the cyclical component of the real interest rate and expected inflation both turned negative. These macroeconomic cyclical components of yields were significantly negative (in the range of -2 to -3 pp) until the end of 2016. Long-maturity bond yields were simultaneously affected by a persisting low term risk premium. The portfolio component of the risk premium also contributed to market yields declining well below their neutral levels. This was linked with increased demand for Czech GBs from non-residents expecting the koruna to appreciate after the CNB discontinued its exchange rate commitment.[12]

In 2017, the CNB ended the commitment and raised monetary policy rates several times. This was reflected in a sizeable absolute decrease in the negative deviation of the real interest rate and expected inflation. The portfolio risk premium deviation also shrank in absolute terms and market yields thus converged partially to their neutral value. Macroeconomic effects continued to show a closing trend in 2018, when the deviation of the real interest rate and expected inflation was smaller than one percentage point. The deviation of the portfolio risk premium for longer maturities even turned positive. However, these effects were offset by a drop in the deviation of term risk premia further into negative figures, especially for the longest maturities. The slope of the market curve thus decreased partially, with the convergence to the neutral curve at the short end not being followed by the long end.

The macroeconomic effects linked with the low-rate environment were thus replaced at the end of 2018 by effects associated with market sentiment expressed by low term risk premia. This can also be seen as meaning that while the monetary policy rate hikes in 2017 and 2018 led to partial closure of the cyclical deviation at the short end of the yield curve, the medium-term effect in the form of a large amount of free liquidity in the Czech financial system

12 See https://www.cnb.cz/en/faq/Exit-from-the-exchange-rate-commitment-00001/.

persisted. This effect was amplified by a persisting environment of low rates in the euro area and surplus liquidity on foreign markets. *Ceteris paribus*, a large volume of liquid assets generally reduces the average yield on total assets, motivating investors to buy higher-yield assets (search for yield). However, a relative shortage of high-yield assets forces investors to lower the risk premia they demand. This also applies to Czech GBs, especially those with longer times to maturity. Such investor behaviour can have implications for financial stability in the form of a risk of sudden and disorderly repricing of risk premia in the event of growth in uncertainty on global financial markets, and hence a correction of GB prices and ensuing losses for GB holders. This observed effect of falling risk premia at a time of rising monetary policy rates is similar to the behaviour of, for example, US yield curves, where this effect can be magnified by perceptions of the US dollar as a global reserve currency.[13]

5. CONCLUSION

This article presented the CNB's approach to constructing the neutral GB yield curve. The latter is an extension of the concept of the natural rate of interest for the Czech Republic described in Hlédik and Vlček (2018). The neutral GB yield curve serves as a benchmark for assessing the position of the economy and the financial system in the macro-financial cycle and also allows us to analyse the cyclicality of risk premia. The method is based on viewing the yield curve in the context of its components – the real interest rate, inflation expectations and the term, credit and portfolio risk premia. We obtain the neutral value of each of these components using two modelling techniques. The neutral yield curve is the sum of the neutral values of the components. Among other things, this approach allows us to identify the causes of the deviation of the yield curve from its neutral value.

By applying the method to Czech GB yields in 2003–2018, we showed that the downward trend in long-term yields was caused by a combination of a decline in neutral yields and cyclicality in yields. Since 2009, market yields have been well below their neutral values. Initially, this was due mainly to a negative deviation of the macroeconomic components of yields (the real interest rate and inflation expectations). In 2017, when the negative deviation of these components began to close, the deviation of risk premia started to decrease. At the long end of the yield curve, record-low risk premia counteracted the effect of monetary policy rate hikes, resulting in a reduction in the slope of the Czech GB yield curve.

REFERENCES

BAUER, M. D. (2017): *A New Conundrum in the Bond Market?* FRBSF Economic Letter 2017-34, Federal Reserve Bank of San Francisco.

BAUER, M. D., RUDEBUSCH, G. D. (2017): *Interest Rates Under Falling Stars* [2017 version], CESifo Working Paper 6571, CESifo Group Munich.

BAUER, M. D., RUDEBUSCH, G. D. (2019): *Interest Rates Under Falling Stars* [January 2019 version], Federal Reserve Bank of San Francisco Working Paper 2017-16. https://www.frbsf.org/economic-research/files/wp2017-16.pdf.

13 This situation – known as Greenspan's conundrum – was first observed in the USA before 2008, when US ten-year government bond yields fell despite rising Fed monetary policy rates. A similar situation has been under discussion since 2017, as long-term US government bond yields have remained relatively low in spite of rising Fed monetary policy rates – see, for example, Bauer (2017).

BLACK, F., SCHOLES, M. (1973): *The Pricing of Options and Corporate Liabilities*, Journal of Political Economy, 81(3), pp. 637–654.

BRZOZA-BRZEZINA, M., KOTLOWSKI, J. (2012): *Measuring the Natural Yield Curve*, National Bank of Poland Working Paper 108, National Bank of Poland.

CNB (2019a): *The Main Instruments of Monetary Policy*, Czech National Bank [online, accessed 21 January 2019]. Available at: https://www.cnb.cz/en/monetary-policy/instruments/.

CNB (2019b): *Financial Market Inflation Expectations*, ARAD Time Series Database [online, accessed 19 February 2019]. Available at: https://www.cnb.cz/cnb/STAT.ARADY_PKG.PARAMETRY_SESTAVY?p_sestuid=21936&p_strid=ACAC&p_lang=EN.

CNB (2019c): *General Government Revenue and Expenditure*, ARAD Time Series Database [online, accessed 15 January 2019]. Available at: https://www.cnb.cz/cnb/STAT.ARADY_PKG.PARAMETRY_SESTAVY?p_sestuid=57021&p_strid=ABC&p_lang=EN.

CZSO (2019): *Inflation, Consumer Prices* [online, accessed 17 February 2019]. Available at: https://www.czso.cz/csu/czso/inflation_consumer_prices_ekon.

DUFFIE, D., KAN, R. (1996): *A Yield-Factor Model of Interest Rates*, Mathematical Finance, 6(4), pp. 379–406.

ECB (2019): *CISS – Composite Indicator of Systemic Stress*, Statistical Data Warehouse [online, accessed 15 January 2019]. Available at: https://sdw.ecb.europa.eu/browse.do?node=9689686.

FAMA, E. F., BLISS, E. (1987): *The Information in Long-Maturity Forward Rates*, American Economic Review, 77(4), pp. 680–692.

FRAIT, J. (2019): *Ten Years Since "Argentina on the Danube"*, čnBlog blog article, published 11 March 2019. Available at: https://www.cnb.cz/cs/o_cnb/cnblog/Deset-let-od-Argentiny-na-Dunaji/.

GAPEN, M. T., GRAY, D., XIAO, Y., LIM, C. H. (2005): *Measuring and Analyzing Sovereign Risk with Contingent Claims*, IMF Working Paper 05/155, International Monetary Fund.

GARCIA-DE-ANDOAIN, C., KREMER, M. (2018): *Beyond Spreads: Measuring Sovereign Market Stress in the Euro Area*, ECB Working Paper 2185, European Central Bank.

HLÉDIK, T., VLČEK, J. (2018): *Quantifying the Natural Rate of Interest in a Small Open Economy – The Czech Case*, CNB Working Paper 7/2018, Czech National Bank.

KUČERA, A., DVOŘÁK, M., KOMÁREK, L., KOMÁRKOVÁ, Z. (2017): *Longer-term Yield Decomposition: An Analysis of the Czech Government Yield Curve*, CNB Working Paper 12/2017, Czech National Bank.

LAUBACH, T., WILLIAMS, J. C. (2003): *Measuring the Natural Rate of Interest*, Review of Economics and Statistics, 85(4), pp. 1063–1070.

MF CR (2019): *SDDS Plus*, Ministry of Finance of the Czech Republic [online, accessed 15 January 2019]. Available at: https://www.mfcr.cz/cs/verejny-sektor/makroekonomika/special-data-dissemination-standard-plus.

NELSON, C. R., SIEGEL, A. F. (1987): *Parsimonious Modeling of Yield Curves*, Journal of Business, 60(4), pp. 473–489.

OECD (2018): *Economic Outlook No 104 – November 2018: Output Gaps: Deviations of Actual GDP from Potential GDP as % of Potential GDP* [online database, accessed 19 December 2018]. Available at: https://stats.oecd.org/index.aspx?QueryId=51655.