DECOMPOSITION OF THE CZECH GOVERNMENT BOND YIELD CURVE

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The term structure of yields is an important source of information on market expectations about future macroeconomic developments and investors' risk perceptions and preferences. This article presents the methodology used by the CNB to obtain such information. It describes the decomposition of the Czech government bond yield curve into its components. The evolution of those components is interpreted in relation to the macro-financial environment. The practical use of the method in the financial sector stress tests conducted by the CNB is then presented.

1. INTRODUCTION

Yields on government bonds (GBs) have been falling across a wide range of countries for more than a decade. This trend is due to several common global factors: savings surpluses in emerging economies and a related build-up of foreign exchange reserves in central banks' balance sheets, global portfolio shifts towards safe assets, and a fall in nominal interest rates linked with the anchoring of inflation expectations at low levels. The decline in yields accelerated after the outbreak of the global financial crisis, when some central banks responded to the adverse economic outlook and deflation pressures by introducing unconventional measures targeted directly at lowering long-term yields.

Czech GB yields, too, have been on a downward trend on average since the global financial crisis started. They have been negative at maturities of up to six years since the beginning of 2016. This can hardly be explained solely by market expectations of continued low rates or by the lower Czech sovereign risk premium. One of the aims of this article is to explain the causes of this trend by decomposing the Czech GB yield curve into components determining the bond yields represented in the yield curve. Another aim is to analyse the behaviour of those components over time, as each component gains significance under different conditions. Last but not least, the aim is to share with the economic community the method used by the CNB to obtain information on the term structure of yields.

The term structure of yields, or the slope of the yield curve, is also an important indicator of the economic cycle. The yield curve aggregates market participants' expectations about the future development of short-term rates, economic activity, inflation and financial risks. Quantifying the effects of various factors on the shape of the yield curve allows us to better understand the extent of possible changes in yields if economic trends continue as they are or change direction and to better estimate the impacts of different economic scenarios on financial market participants. By decomposing the yield curve, the CNB gains an important source of information for monetary[1] and prudential policy purposes.

The article is structured as follows. Section 2 presents the method used to decompose yield curves. In section 3, the zero-coupon Czech GB yield curve is decomposed into four components and the factors that influence them are empirically analysed. In section 4, the analysis focuses on the use of the components to create scenarios for the CNB's macro stress tests of the financial sector. The final section concludes.

2. METHODOLOGY USED TO DECOMPOSE THE CZECH GOVERNMENT BOND YIELD CURVE

The yield curve is made up of yields on bonds with various residual maturities at a specific point in time. The shape of the curve is determined by its level (the position of the short end of the curve), its slope (the difference between yields on short- and long-maturity bonds) and its curvature (the maturity-yield relationship is not necessarily linear, but can be concave or convex). The relative level of short-term and long-term yields should depend on market expectations about the future path of short-term rates. According to the pure expectations hypothesis, a risk-neutral investor should attain the same yield from investing in a long-term bond as from a series of investments in a short-term bond over a period equal to the residual maturity of the long-term bond. The pure expectations hypothesis offers a simple and attractive interpretation of the yield curve. However, it does not hold in reality, as it does not take risk-averse investors into consideration. In other words, investors perceive long-term investment as uncertain and demand a risk premium.

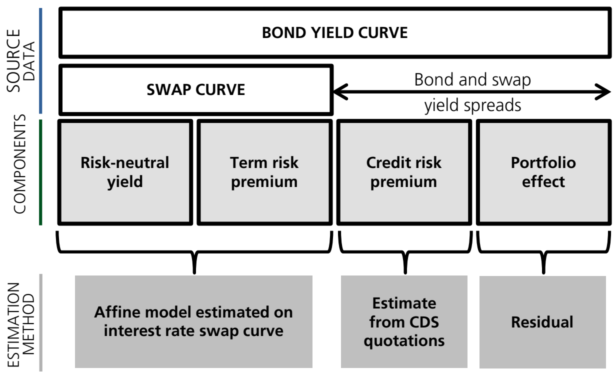
1 The use of Czech GB yield curve decomposition for monetary policy purposes is not covered in this article but does form part of research project C7/16 "Longer-term Yield Decomposition: The Analysis of the Czech Government Yield Curve", with an output scheduled for the end of 2017.

That premium consists of several sub-premia reflecting different sorts of risks having varying degrees of significance over time and for different maturities. So, to properly understand the evolution of the yield curve, we need to decompose it.

We decompose the Czech GB yield curve into four components (see Chart 1): a risk-neutral yield, a term premium, a credit risk premium and a portfolio effect. The first two components were obtained by decomposing the swap yield curve, as the rate of the interest rate swap is made up almost exclusively of the risk-neutral yield and the term premium (see section 2.1). The other two components correspond to the difference between the GB yield and the swap rate for the relevant maturity. The breakdown of this residual between the credit risk premium and the portfolio effect is based on the estimate of the credit risk premium.

CHART 1

COMPONENTS OF THE SWAP AND BOND YIELD CURVES



Source: Authors
Note.: CDS = credit default swap.

The *risk-neutral yield* reflects expectations about future monetary policy and economic developments. If investors expect the monetary policy rate to rise in the future, they also expect the rate of return on holding and regularly reinvesting short-term bonds to go up gradually. The *term premium* relates to the maturity of the bond and is compensation for interest rate risk. It takes into account investors' uncertainty about the future path of the short-term rate. Committing to long-term bonds will turn out to be relatively less (more) advantageous if future short-term rates are higher (lower) than originally expected. For the relevant maturities, risk-neutral yields and the term premia of bonds are identified with the risk-neutral yield and term premium obtained from the decomposition of the swap curve (see section 2.1), because for bond yields and swap rates these two components are determined by the same fundamentals.

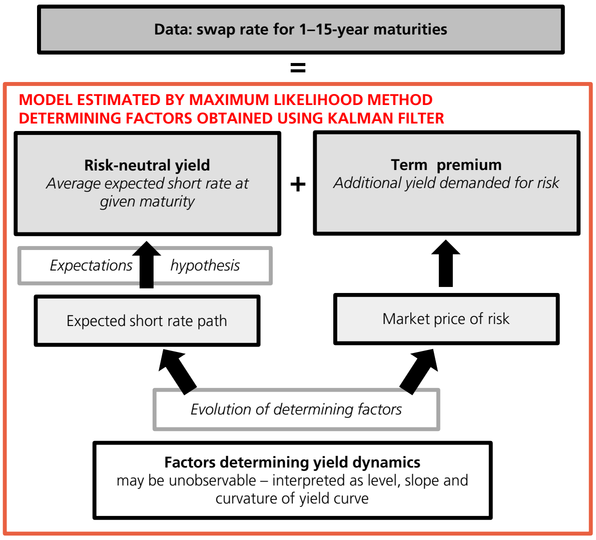
The *credit risk premium* is compensation for the risk that bond coupons and principal will not be paid on time and/or in full. This premium tends to increase with increasing maturity. The issuer's position can worsen significantly over time, so, for example, the one-year probability of default in five years' time (i.e. the probability of default between the fifth and sixth years) is usually higher than the current one-year probability of default, i.e. the probability of default between now and 12 months from now (Moody's, 2016). The credit risk premium was estimated from credit default swap (CDS) quotations for Czech GBs.[2] Month-end CDS quotations for maturities of 1–5, 10, 20 and 30 years were used in the estimation.[3] The volatility of the CDS quotations was reduced by smoothing them using the three-month moving average. From these averages, we estimated the Nelson-Siegel function (Nelson and Siegel, 1987) in each period of interest and in this way calculated the CDS spreads and the Czech GB credit risk premium for all the necessary maturities.[4]

The *portfolio effect* of the yield reflects demand for GBs as an investment asset. Many investors prefer GBs to other assets, mainly because of their low credit risk, their relatively high market liquidity, their low haircuts when used as financial collateral and their preferential regulatory treatment. The portfolio effect is calculated as the difference between the GB yield and the rate of an interest rate swap of identical maturity minus the credit risk premium. The average portfolio effect in the model therefore depends on the estimate of the credit risk premium. The portfolio effect can take positive (negative) values if the yield demanded by the investor for holding the bond is higher (lower) than the expected short-term rate plus the term premium and the credit risk premium.

2 The advantages of this approach are the objective existence of quotations (which should represent the direct cost of hedging credit risk), its forward-lookingness and the availability of any periodicity. On the other hand, we also need to take into account certain sovereign CDS market anomalies that may limit the use of CDS quotations as a sovereign solvency indicator (see Komárek et al., 2013, Box 4 of FSR 2009/2010 and Box 4 of FSR 2011/2012). Short time series are another potential limitation for some maturities.
3 We included CDS quotations with 20-year and 30-year maturities in the estimation because of the absence of quotations for 15-year CDS.
4 CDS quotations for Czech public debt of shorter maturities are close to those of longer maturities. However, this was not reflected in the yields on Czech GBs of short maturities. The Nelson-Siegel function was therefore specified so that the credit risk premium converged to zero with decreasing maturity.

CHART 2

SCHEME OF SWAP CURVE DECOMPOSITION USING THE AFFINE MODEL



Source: Authors

2.1 Koruna swap yield curve decomposition methodology

The swap yield curve was decomposed using the affine model[5] (Duffie and Kan, 1996, or Málek, 2005), which belongs to the category of factor models. The basic building block of this model is its assumption that there are several factors that determine the entire term structure of yields. The model presented here uses three factors, in line with the standard approach employed in the literature (Litterman and Scheinkman, 1991). These factors can be either observable[6] – such as macroeconomic variables (Ang and Piazzesi, 2003) or yields on particular bond portfolios (Joslin et al., 2011) – or unobservable. For the purposes of the model presented here, we consider unobservable factors. The three factors are estimated within the model and, depending on their dynamics, can be considered as the level, slope and curvature of the yield curve.

The relationship between the swap rate and the three unobservable factors runs via two fundamental variables (see Chart 2). The first is the short-term (instantaneous) risk-free rate and the second is the risk premium demanded by investors.

The short-term (instantaneous) risk-free rate[7] is determined in the model as a linear function of the three unobservable factors. The yields for longer maturities are then derived from it. If investors were risk-neutral, the expected average of the future short-term rate at a particular point in time would be equal to the present yield on a bond of corresponding maturity. We refer to long-term yields determined as the expected average of the future short-term rate as **risk-neutral yields** (see the left-hand side of Chart 2).

However, investors are usually risk-averse and therefore demand a risk premium. In the affine model, this is a function of the **market price of risk**, which expresses the uncertainty about the future evolution of the unobservable factors and is a linear combination of those factors (see the right-hand side of Chart 2). In the case of the swap curve, the risk premium takes positive values. Swap rates contain hardly any credit risk premium, as no principal is paid, coupon payments are netted and the way swaps are traded mitigates counterparty risk. A swap is meanwhile not an investment asset, because it cannot be used to deposit liquidity. The portfolio effect of a swap is therefore negligible. For these reasons, the model assumes that the risk premium of an interest rate swap is made up solely of the **term premium**.

The main reason for estimating risk-neutral yields and the term premium from the swap yield curve is the aforementioned absence of a credit risk premium and a portfolio effect. These two components can be affected in certain circumstances by specific market effects such as flight to quality, flight to liquidity, search for yield and various types of speculation caused, for example, by unconventional monetary policies. However, these specific effects could disrupt the affine model's assumption of market efficiency and the impossibility of arbitrage. The risk-neutral yield and the term premium estimated using the

5 The name "affine model" reflects the fact that the short-term rate and the price of risk are both specified as affine transformations – with some simplification, linear combinations – of the determining factors. Consequently, the yields can also be expressed as a linear combination of the determining factors, which greatly facilitates the subsequent estimation of the model parameters. Another widely used model is the "LIBOR market model" (LMM; see, for example, Gatarek et al., 2006). The advantage of the LMM is its ability to price interest rate derivatives more accurately. On the other hand, it is more complicated and advanced numerical methods are needed to estimate it. Given our aim of analysing the yield curve for financial stability purposes, we therefore regard the affine model as more suitable.

6 Models with observable factors are technically simpler. They can often be solved using the least squares method. On the other hand, they involve making assumptions about macrofinancial relationships and specifically choosing the main determinants of yields. They are also associated with a risk of omission of important variables.

7 The short-term (instantaneous) risk-free rate is not observable in the market. However, it is linked to some extent with the overnight rate on the interbank market and the monetary policy rate.

affine model from government yield curves could thus be distorted.

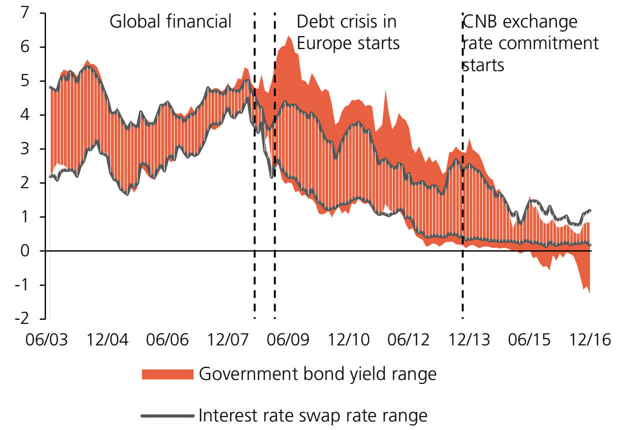
In the affine model presented here, it is also necessary to consider the possibility of interest rates reaching their lower bound. This causes asymmetry in the future path of interest rates. If interest rates are already very close to their lower bound, the probability of them falling further is lower than the probability of them rising. To take this asymmetry into account, the model uses the concept of shadow rates (Krippner, 2013).[8] This concept is used not to extract the shadow rates for their own good, but to ensure that the model is internally consistent.

The model parameters are estimated by the maximum likelihood method using the Kalman filter to obtain the unobserved factors (Durbin and Koopman, 2012).

CHART 3

RANGES FOR ZERO-COUPON CZECH GOVERNMENT BOND YIELDS AND KORUNA INTEREST RATE SWAP RATES

(%, ranges between 1Y and 15Y maturities)



Source: Bloomberg, PSE, MtS Czech Republic, Thomson Reuters, authors' calculations

Note: Vertical lines mark the last monthly observation before the event described. The start of the global financial crisis is related to the collapse of Lehman Brothers in September 2008. The start of the debt crisis is related to the negative assessment of Greek public finances by the IMF and the EC in February 2009.

3. RESULTS OF THE DECOMPOSITION OF THE CZECH GOVERNMENT BOND YIELD CURVE

The yield curve is decomposed using the yields on zero-coupon bonds of relevant maturities, since those yields are not affected by the size and distribution of the coupons over the life of the bond and hence are an exact indicator of the rate of return demanded for investing for the relevant time period.[9] For this reason, a zero-coupon curve was constructed using Czech government bonds in Czech koruna. As the risk-neutral yield and the term premium are estimated using swap rates, it was also necessary to construct a zero-coupon koruna swap curve. The two zero-coupon curves were constructed for maturities of 1 to 15 years[10] as of the end of each month over the period of 7/2003–12/2016. The Fama-Bliss bootstrap method (Fama and Bliss, 1987), which assumes constant forward rates among the closest maturities, was used for the construction. The advantage of this method over the alternatives (such as Nelson and Siegel, 1987, or Svensson, 1994) consists in its ability to replicate any yield curve shape exactly, which eliminates problems with imperfect fit on some segments of the curve.

The maturity spreads for zero-coupon GB yields and swap rates in 2003–2016 show mixed developments (see Chart 3). Until the outbreak of the global financial crisis in September 2008, yields and rates followed similar patterns. From then until the second half of 2009, yields were affected by the fear of the emerging debt crisis in Europe. Owing to the responses of the various relevant authorities to the crisis, yields began to trend downwards in mid-2009 and a positive gap opened up between yields and rates at longer maturities. At the end of 2013, yields started falling faster than rates – until 2015 for long maturities and then exclusively for short maturities. It is clear from this simple historical excursion that yields and rates were affected by different factors with different intensity, including for individual maturities.

The zero-coupon Czech GB yield curve was decomposed into the four introduced components for one-year and ten-year maturities (see Charts 4 and 5). In the case of the one-year bond, it is clear that yield was made up predominantly of the risk-neutral yield until the global financial crisis broke out in 2008 (see Chart 4). From the end of 2008 onwards, the one-year bond yield declined due to a falling risk-neutral yield. The decline in this component was linked with market expectations that short-term rates would stay very low. In addition, starting in the second half of 2008, key central

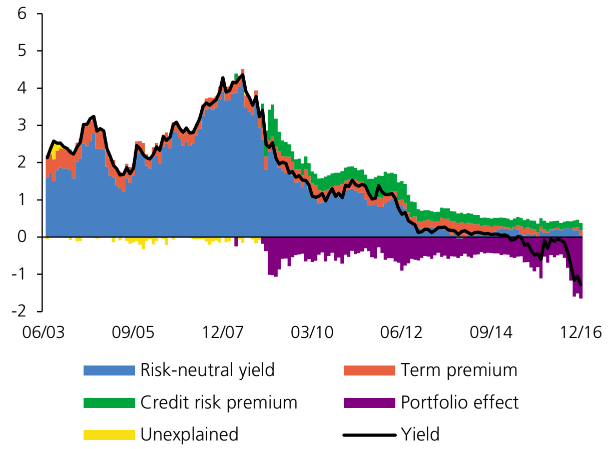
8 In this concept, the yield on investing in a bond equals the sum of the yield on investing in a shadow bond whose yield is not bounded below by zero and the yield from the sale of an option to purchase that bond at a price equivalent to the yield at the lower bound. For details, see Krippner (2013).

9 The use of coupon bonds could potentially lead to underestimation of the yields demanded for a given maturity (Livingston and Jain, 1982).

10 The range of maturities considered was chosen with regard to data availability and quality. Bonds with maturities of less than one year are not used in such studies because their prices can be distorted by specific effects due to lower liquidity (BIS, 2005). In addition, koruna interest rate swaps are not available for maturities of less than one year. The time series for bonds and swaps with maturities of over 15 years are shorter and their prices may be less reliable due to their lower trading volumes.

CHART 4

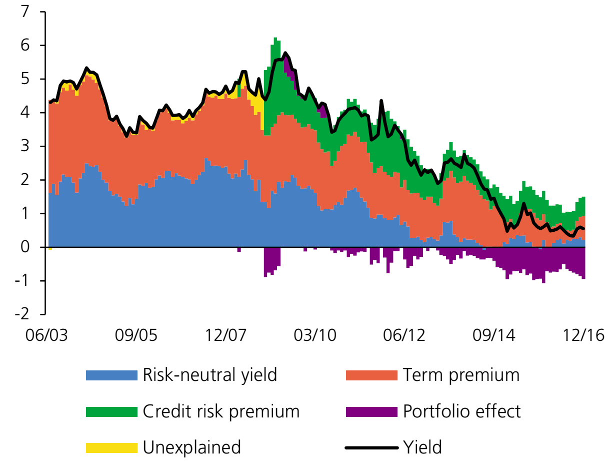
DECOMPOSITION OF THE 1-YEAR ZERO-COUPON BOND YIELD
(%)



Source: Bloomberg, PSE, MtS Czech Republic, Thomson Reuters, authors' calculations
Note.: Reliable data on CDS quotations are not available until 2008. As a result, the difference between the bond yield and the swap rate could not be decomposed and is reported as *Unexplained*.

CHART 5

DECOMPOSITION OF THE 10-YEAR ZERO-COUPON BOND YIELD
(%)



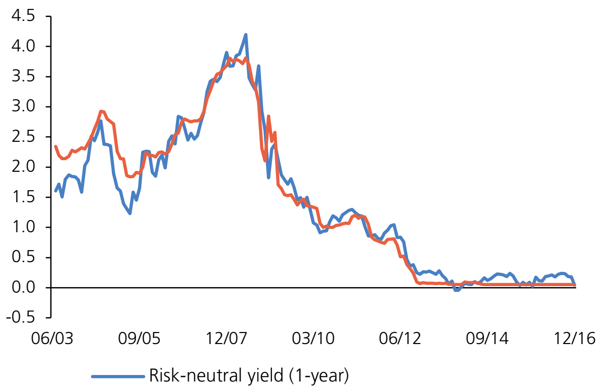
Source: Bloomberg, PSE, MtS Czech Republic, Thomson Reuters, authors' calculations
Note.: Reliable data on CDS quotations are not available until 2008. As a result, the difference between the bond yield and the swap rate could not be decomposed and is reported as *Unexplained*.

banks gradually released large amounts of liquidity as part of their monetary and lender-of-last-resort policies. For reasons of flight to quality and search for yield, Czech GBs represented an attractive opportunity for foreign investors. Owing to the negligible risk of sovereign default over such a short time scale, the credit risk premium was relatively low in the period under review. The negative portfolio component was linked with investors' preference for holding shorter-maturity bonds at a time of market stress. In 2015, the portfolio component exceeded all the other components combined for the first time and the one-year bond yield thus turned negative. Since then, the yield on short-maturity Czech GBs has reflected strong interest among foreign investors speculating on appreciation of the Czech koruna against the euro upon the exit from the CNB's exchange rate commitment (see section 2.1 of this Report).

The significance of the different components in the level of the ten-year Czech GB yield changed substantially over the 13 years under review (see Chart 5). Until the global financial crisis broke out, ten-year bond yields were almost equal to swap rates of the same maturity. The risk-neutral yield and the term premium each made up around half of the yield. When the US investment bank Lehman Brothers collapsed in mid-September 2008, the global financial market situation worsened sharply. Uncertainty and risk aversion increased, giving rise to higher market price volatility. Owing to the high level of global market integration, the market stress passed to the Czech GB market, as evidenced by growth in the credit risk premium. In mid-October 2008, market liquidity on the Czech GB market dropped sharply as a result of excess supply of Czech GBs from foreign institutional investors. The CNB responded by introducing extraordinary liquidity-providing repo operations in which Czech GBs were accepted as eligible collateral for the first time. This fostered a slight reduction in the credit risk premium. For the same reasons as for the one-year bond, the risk-neutral yield and the term premium began to fall in mid-2008. The term premium increased in late May/early June 2013 in response to a change in market expectations about the timing of the tapering of bond purchases by the US Federal Reserve in the QE3 programme. This change in expectations triggered an unusually sharp price adjustment in a whole range of asset categories across global markets, accompanied by market turbulence. In November 2013, however, the ECB reduced its base rate and in June 2014 it announced the use of other unconventional instruments, including a plan to purchase euro area GBs. In November 2013, the CNB started to use the koruna exchange rate as an additional monetary policy instrument. This combination of measures led not only to a fall in the term premium of the ten-year bond, but also to a negative portfolio component. From 2011 onwards, the credit premium and the portfolio component were also affected by the debate about, and subsequent phasing in of, new financial market regulatory measures (Basel III, CRD IV/CRR). A signal of preferential treatment of GBs in the capital and liquidity requirements was sent out to the market.

CHART 6

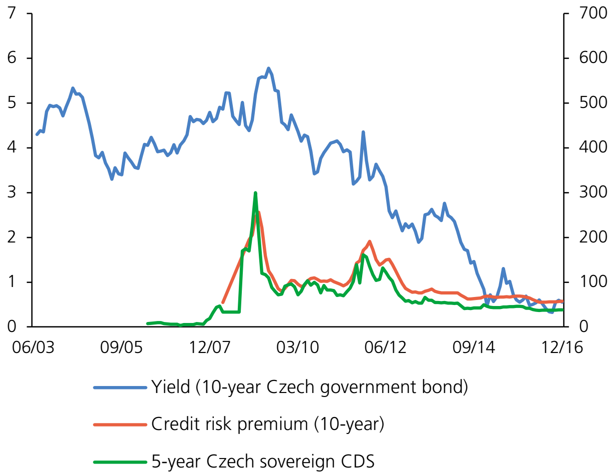
COMPARISON OF THE 1-YEAR RISK-NEUTRAL YIELD WITH ANALYSTS' FORECASTS
(%)



Source: CNB
Note: Expectations represents the average CNB 2W repo rate expected one year ahead at the given moment. It is calculated as 1/26 * current repo rate + 25/26 * (0.5 * repo rate expected one month ahead + 0.5 * repo rate expected one year ahead). The one-month-ahead and one-year-ahead expectations are the averages of the analysts forecasts taken from the CNB's Financial Market Inflation Expectations Survey for the given month.

CHART 7

THE CREDIT RISK PREMIUM AND THE CDS SPREAD
(left-hand scale: %, right-hand scale: bp)



Source: Bloomberg, PSE, MtS Czech Republic, Thomson Reuters, authors' calculations
Note: The estimated credit risk premium for the 10-year bond. The difference between the 5-year CDS and the 10-year credit risk premium is due to the difference in maturities.

In order to confirm the theoretical interpretation of the estimated components, their profiles were compared with those of selected macroeconomic and financial variables with which they should theoretically be closely linked.

The *risk-neutral yield* should match market expectations about future short-term rates. A comparison with analysts' expectations about the CNB's two-week repo rate one year ahead confirmed this theoretical assumption (see Chart 6). The correlation between risk-neutral yields and expected rates also turned out to be higher than that between risk-neutral yields and actual rates (see Table 1).

The *term premium* should theoretically be closely correlated with the level of difficulty in forecasting future short-term rates at a given maturity horizon. Forecasting difficulty is hard to measure, so it was proxied by the variability of the last four monthly values of the forecasted variables. The correlation between the term premium and the variability of inflation, inflation expectations and expectations about the CNB's two-week repo rate was relatively low (see Table 1). This may have been caused by the backward-looking nature of these imperfect measures of forecasting difficulty. Conversely, a relatively strong correlation between the term premium and the present and expected interest late level lent some support to the theoretical assumption. Generally speaking, when interest rates are low, their volatility is also low. This enables investors to make better forecasts and demand a lower term premium.

The *credit risk premium* should be correlated with investor perceptions about Czech GB credit risk. Given the method for estimating the credit risk premium, the correlation between it and CDS spreads was very high (even with CDS spreads of other maturities; see Chart 7 and Table 1). Another market indicator of credit risk – the spread between Czech and German five-year GB yields – was also highly correlated with the credit risk premium. By contrast, a fundamental often used to express the level of sovereign credit risk – the ratio of GBs issued to GDP – had only a limited correlation with the credit risk premium. This may be due to the relatively low Czech public debt level. A closer relationship between the public-debt-to-GDP ratio and the sovereign credit risk premium does not usually surface until public debt exceeds a certain level. For many reasons, moreover, that level differs from country to country and for some countries is below the often cited 60% level (Banque de France, 2012).

The credit risk premium turned out to be closely correlated with short rates and market uncertainty indicators. Higher interest rates potentially push up the costs of government financing and hence also partially increase the probability of sovereign default. Global uncertainty as measured by the VIX index and uncertainty on the interbank market as measured by the difference between the three-month PRIBOR and the three-month koruna OIS rate were more significantly correlated with the credit risk premium. This was probably linked with the rising share of non-residents in

TABLE 1

CORRELATION BETWEEN THE COMPONENTS OF THE 10-YEAR ZERO-COUPON BOND AND ECONOMIC AND FINANCIAL VARIABLES

Type of variable	Name of variable	Risk-neutral yield	Term premium	Credit risk premium	Portfolio effect
Macroeconomic	Inflation (CPI)	0.50	0.42	0.67	0.12
	GDP growth	0.27	0.15	-0.49	-0.54
	CZK/EUR exchange rate	0.29	0.45	-0.27	-0.53
Short interest rates and market expectations	CZEONIA index	0.86	0.73	0.69	0.38
	CNB 2W repo rate (current)	0.88	0.76	0.77	0.36
	3M PRIBOR	0.87	0.74	0.78	0.38
	3M OIS in CZK	0.88	0.76	0.74	0.37
	CNB 2W repo rate (1-year expectations)	0.95	0.79	0.57	0.53
	Inflation (1-year expectations)	0.75	0.65	0.39	0.40
Fluctuations in short interest rates and market uncertainty	Variability* of inflation	0.25	0.29	0.51	-0.01
	Variability* of 1-year inflation expectations	0.30	0.14	0.23	0.13
	Variability* of 1-year expectations about CNB 2-week repo rate	0.35	0.42	0.70	0.07
	VIX volatility index	0.14	0.17	0.72	0.13
Credit risk of Czech state and Czech interbank market	Czech GBs issued/GDP	-0.44	0.25	-0.02	0.37
	5-year CDS spread for Czech GB	-0.06	0.13	0.93	0.15
	Spread between 3-month PRIBOR and 3-month OIS	-0.14	0.01	0.59	0.24
	Spread between Czech and German 5-year GB yields	-0.13	-0.07	0.82	0.37
Investment flows	Czech GB trading volume	-0.05	0.11	0.28	-0.01
	Proportion of foreign holders of Czech GBs	-0.33	-0.73	-0.49	-0.62
	Profit on hedged investment in Czech GBs**	-0.45	-0.59	-0.38	-0.52
	Net portfolio and other investment in balance of payments	0.06	0.21	0.17	0.06

Colour scale for Pearson's correlation coefficient

-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1

Source: PSE, Bloomberg, CNB, MtS Czech Republic, Thomson Datastream, authors' calculations
Note: The explanatory power of the correlations may be limited by the short length and the existence of a trend for some of the time series.
* Variability is measured by the standard deviation of the last four monthly observations.
** The average profit on (1) an investment consisting in converting euros into korunas, depositing them at the CNB deposit rate and then converting them back into euros at the 3-month forward rate, and (2) an investment consisting in converting euros into korunas, buying a 2-year Czech GB and then converting it back into euros at the 2-year forward rate. The return that could have been achieved by depositing the funds for three months at the ECB deposit rate was deducted from the first investment and the 2-year German GB yield was deducted from the second.

public debt holdings and with the use and pricing of GBs as financial collateral on secured money markets.

The *portfolio effect* should theoretically be linked with investors' preference for Czech GBs over other assets – dominated in korunas or other currencies. We used four variables to express this preference. First, we looked at the correlations between the portfolio effect and the inflow of short-term foreign assets into the Czech economy and the Czech GB trading volume. In both cases, the correlation was low. Then we used the stock indicator of the proportion of Czech GBs held by non-residents. It was correlated strongly negatively with the portfolio effect. A stronger correlation was also found between the portfolio effect and the profit on investing in Czech assets with simultaneous exchange rate risk hedging (i.e. purchasing korunas on the spot market, depositing those korunas or buying a short-term bond and then converting back at the forward exchange rate). Rising yields on this type of investment were associated with a lower portfolio effect. Both negative correlations can be interpreted as meaning that an inflow of foreign portfolio investment motivated by hedged profits boosts demand for Czech GBs as an attractive instrument, causing their yields to turn negative.

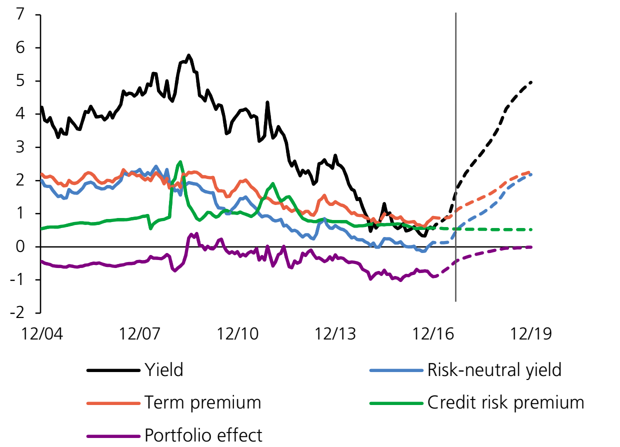
4. USE OF YIELD CURVE DECOMPOSITION IN FINANCIAL STABILITY ANALYSES

The yield decomposition described above can be used in financial stability analyses to identify potential market risks and to create scenarios for stress testing financial institutions. The Financial Stability Report regularly discusses the current level of interest rates and the risks associated with their future path. Knowledge of the individual components allows us to expertly assess the probability of

CHART 8

THE 10-YEAR BOND YIELD IN THE BASELINE SCENARIO

(%)



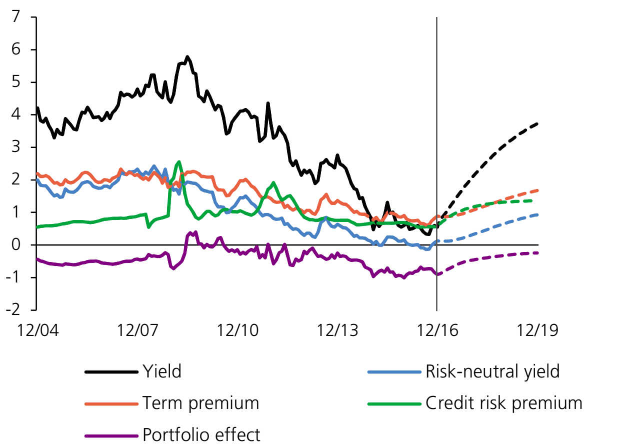
Source: Bloomberg, PSE, MtS Czech Republic, Thomson Reuters, authors' calculations

Note: The vertical line separates the historical values (solid lines) from the values simulated in the scenario (dashed lines).

CHART 9

THE 10-YEAR BOND YIELD IN THE ADVERSE SCENARIO

(%)



Source: Bloomberg, PSE, MtS Czech Republic, Thomson Reuters, authors' calculations

Note: The vertical line separates the historical values (solid lines) from the values simulated in the scenario (dashed lines).

the current trends continuing or reverting and to monitor the interaction of components that ameliorate or multiply potential shocks (see section 2.1 of this Report).

Yield curve decomposition can also be used in simulation analyses, including stress tests. The impacts of changes in the Czech GB yield curve are analysed in the CNB's regular financial sector sensitivity analyses and stress tests (see section 4 of this Report). Previously, the CNB had simulated the evolution of "only" three yield curve maturities and had not linked them directly to the other macrofinancial variables used.[11] Decomposition of the yield curve into its components allowed it to calibrate the scenarios more accurately by linking yields to other variables entering the scenarios.

The yield for each maturity takes a unique value for each of the components. With 15 maturities and four components, this implies 60 variables. To use the components to forecast the behaviour of the yield curves in the stress scenarios, we had to reduce the number of variables. We thus used the Nelson-Siegel function to calculate the level and slope of the term structure (15 maturities) of each component. In this way, we replaced the term structure of each component with "only" two variables. The level and slope of each component are then inputted along with the economic and financial variables into a dynamic factor model.[12] The model is used in conjunction with the scenario for the future evolution of macroeconomic variables (inflation, GDP growth, the exchange rate and the 3M PRIBOR) to predict the paths of the components (see section 4 of this Report). The bond yields (swap rates) are then calculated from the predictions of the components as the sum of all the components (the sum of the risk-neutral yield and the term premium respectively).

The use of this method in stress testing can be demonstrated on the example of the ten-year GB. To simulate its yields, we used the November 2016 *Baseline Scenario* and *Adverse Scenario* (CNB, 2016). The *Baseline Scenario* (see Chart 8) was associated with a rise in inflation, GDP growth and the 3M PRIBOR and with appreciation of koruna over a three-year horizon. Positive economic developments resulted in sharp growth in risk-neutral expectations about the short rate. Interest rates moved out of the narrow band near the lower bound, leading to expectations of greater volatility of the short rate and hence also to growth in the term premium. At the same time, the favourable economic conditions caused the credit risk premium to stay at a low level. By contrast, the portfolio effect had a large upward effect on yields, as non-resident speculators were expected to leave the market after the

11 These variables are generated by the CNB's forecasting model (G3; Andrle et al., 2009; Brázdik et al., 2011).

12 This model is different from the affine model presented in section 3. The affine model generates the components, whereas this model produces an estimate of the common evolution of those components and the macroeconomic variables from the stress scenarios.

CNB's exchange rate commitment was discontinued. Over a three-year horizon, these factors combined caused the ten-year yield to rise to 5%, close to the levels recorded before the global financial crisis.[13]

In the *Adverse Scenario* (see Chart 9), which assumed a return to recession, the ten-year yield went up to around 3.7%. Owing to continued accommodative monetary policy, risk-neutral yields and the term premium increased very modestly. In line with the return to recession, the model expected credit risk to rise, although the credit risk premium reached lower values than it had during the debt crisis in Europe. Uncertainty on financial markets then led to an outflow of foreign investors, causing the portfolio effect to rise. This rise was moderate, however, as some investors (including domestic financial institutions) still saw Czech GBs as an attractive investment given their low risk level compared to alternatives in other countries.

5. CONCLUSION

The yield curve is an important indicator of the economic cycle, as it aggregates the expectations of market participants. The factors that affect the shape of the yield curve do so to different extents in different circumstances. To interpret the evolution of the yield curve correctly, it is therefore useful to decompose it. This article presented the method used by the CNB to decompose the Czech government bond yield curve.

We decomposed the Czech GB yield curve into four components: a risk-neutral yield, a term premium, a credit risk premium and a portfolio effect. The first two were obtained by decomposing the zero-coupon koruna swap curve using the affine model. The credit risk premium was estimated from credit default swap quotations for Czech GBs. The portfolio effect formed the residual.

A comparison of the four estimated components with selected macroeconomic and financial variables confirmed the strong theoretical interpretation of these components. As the theory had anticipated, for example, the risk-neutral yield matched analysts' expectations about future short-term policy rates, and the portfolio effect became highly negative as the removal of the CNB's exchange rate floor neared.

13 This trend is strongly affected by the Baseline Scenario's assumption of growth in the 3M PRIBOR to 3% at the three-year horizon.

The above decomposition allowed for a more detailed interpretation of the level of Czech yields and associated risks for the purposes of financial stability analyses. The macroeconomic scenarios used by the CNB were calibrated more accurately by linking the individual components of yields to other macroeconomic and financial variables. The Czech GB yield curve decomposition method described in this article was used to create stress scenarios for the first time in the present Financial Stability Report.

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