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# Long-term sovereign interest rates in Czechia, Hungary and Poland: a comparative assessment with an affine term structure model

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## ABSTRACT

This paper provides a comparative evaluation of the behaviour of long-term sovereign yields in Czechia, Hungary and Poland from 2001 to 2019. An affine term structure model developed by Adrian, Crump and Moench (2013) is used as an empirical framework for the decomposition of the bond yields into term premium and risk-neutral components. We document a substantial compression in term premia which started in Central European economies around 2013 and played a decisive role in the changes that occurred in 10-year sovereign yields. This pattern, however, was more prevalent in Czechia and Poland than in Hungary. We show that long-term rates in all three economies remained higher than in Germany due to relatively large risk-neutral components. Nevertheless, cross-country correlations became increasingly dependent on term premium dynamics, both among Central European economies and between each of them and Germany. These results are robust to bias-correction in the baseline models and interpreted in the light of the general interest rates decline in the global economy. Potential policy implications are also discussed.

**Key words:** long-term interest rates, affine term structure model, term premium, risk-neutral rates, Central Europe.

## 1. Introduction

This paper investigates sovereign long-term interest rates in Czechia, Hungary, and Poland in an attempt to provide a detailed account of their behaviour from 2001 to 2019. Are the 10-year government rates mostly driven by a term premium component that investors demand for holding such securities, or by an expected path of short-term interest rates (i.e. risk-neutral rates)? Why did they decline by so much from the early 2000s, and so sharply after 2013? Is there a strong international comovement in long-term rates among the three economies, and how do they depend on foreign bond yields? The answers to these questions pose an empirical challenge but have weighty implications for both the broader economy and policy-making. Long-term yields and their components convey rich information about current and future states of an economy, for instance about expected trends in investment and consumption. They are, at the same time, a key variable for governments and central banks, with consequences for public debt management and monetary transmission mechanism (Gürkaynak and Wright, 2012). Central European (CE) economies constitute an interesting case study of long-term rates for two additional reasons. First, long-term rates are an essential channel of cross-border propagation of shocks, and the case of CE

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economies provides further evidence on the nature of comovement in interest rates and the impact of the international financial factors on a small open emerging economy. Second, 10-year sovereign rates are among the benchmarks for convergence between CE economies and the euro area. Hence, they remain relevant in the discussion on international economic and financial integration of these countries.

The empirical strategy of this paper builds upon an affine term structure model developed by Adrian, Crump and Moench (2013) (henceforth: ACM), a tractable method to perform a yield curve decomposition using a sequence of linear regressions. The estimation of this model makes use of a set of sovereign bond yields of various maturities to disentangle Czech, Hungarian, and Polish 10-year yields into risk-neutral components (expectations of the short-term rate) and term premia. Next, we employ these estimates to assess changes in long-term interest rates in each of the countries. Our study is among the first to provide a comparative analysis of 10-year treasury yields in all three CE economies using structural yield curve modelling and to present a comprehensive explanation of shifts in long-term rates and their cross-border linkages. As an extension to the main part of the analysis, we examine the small sample bias correction of the baseline ACM model.

We arrive at three main conclusions. First, we find a substantial term premium compression that started around 2013 in all three economies and brought those components to very low (Hungary) and possibly negative levels (Czechia and Poland). Second, we show that shifts in term premia components played a decisive role in the behaviour of 10-year sovereign yields. This pattern was more prevalent in Czechia and Poland than in Hungary but post-2009 the relative importance of term premium components increased in all three countries. Third, we demonstrate that long-term rates in CE economies were higher than in Germany, their leading economic and financial partner, due to relatively larger risk-neutral components. At the same time, cross-country correlations in the long-term yields were increasingly more dependent on the term premium dynamics, both among the three CE economies and between each of them and Germany.

The paper is organised as follows. The next section briefly discusses the research background and recent studies in the area. Section 3 presents the dataset of sovereign bond yields. Section 4 provides an overview of the affine term structure model used in the paper. The empirical outcomes are laid out in Section 5, while Section 6 discusses the results. The final section concludes.

## 2. Related literature

After the period of "benign neglect" (Turner, 2013), the long-term interest rates entered the centre of macroeconomic policy debate. Starting from the 2000s, sudden or unexpected shifts in those rates, exemplified by Greenspan's "conundrum" of 2004-2006 (Rudebusch, Sack and Swanson, 2007), drove more of the attention to macroeconomic effects of changes at the longer end of the yield curve. This concern intensified once new tendencies appeared in the global economy: persistently low inflation rates and inflation expectations, looming secular stagnation (Eggertsson, Mehrotra and Summers, 2016), prolonged quantitative easing and its subsequent tapering by the Federal Reserve (Kuttner, 2018), global shortages of safe assets (Caballero, Farhi and Gourinchas, 2017), or constraints to fiscal policy (Blanchard, 2019). As of more recently, markets got troubled with the dynamics of bond markets during the COVID-19 pandemic crisis.

From the point of view of small and open CE economies, the importance of long-term interest rates is further magnified by international linkages in bond yields (Obstfeld, 2015). The global financial cycle, whereby shocks in "central" economies, i.e. the US or the euro area, are transmitted to other countries, is consequential for capital flows, exchange rates, or monetary spillovers to such countries (Rey, 2016). This may also produce externalities for local bond markets and have an impact on domestic economies (Kolasa and Wesołowski, 2020). There is now accumulating evidence that a substantial part of spillovers from the ECB's monetary policy, both standard and non-standard one, is transmitted to CE economies via sovereign bond yields (Grabowski and Stawasz-Grabowska, 2020; Janus, 2020). Hence, the detailed evidence on the long-term interest rates is of sheer importance to policymakers in the CE countries, because exogenous movements in these yields may hamper the ability to influence interest rates on the longer end of the yield curve. As such, long-term rates are also worth investigating in the context of Czech, Hungarian, and Polish monetary policy effectiveness under financial globalization.

The empirical research on long-term bonds decomposition focuses mostly on the US and other advanced economies. The studies in this area often use dynamic term structure models and demonstrate that advanced economies exhibit similar patterns of changes in long-term interest rates, mostly due to comovement in term premium components that are subject to inflation shocks and international liquidity conditions (Wright, 2011). It is also shown that changes in long-term yields are amplified by global risk factors and international effects of monetary easing (Abbritti et al., 2018). Using international panel datasets that cover the CE economies, Mehrotra, Moessner and Shu (2019) and Albagli et al. (2019) both find that risk-neutral and term premium components of 10-year yields played a role in an intensification of monetary policy spillovers from the US to the rest of the world post-2009. However, their conclusions on the relative importance of those components for spillovers to advanced and emerging economies are mixed.

To the best of our knowledge, there is a shortage of comparative analyses on the long-term interest rates in Czechia, Hungary, and Poland that would employ empirical term structure modelling. Several studies deal with long-term yields through the lens of such a framework in individual CE economies. In the Czech case, Dvorák, Komárková and Kucera (2019) use an affine model along with the CDS quotations to retrieve components of long-term yields in Czechia. They attribute the post-crisis decline in these rates mostly to the portfolio effects, such as flight to quality. Interest rate expectations and term premium components in Hungary are analysed by Horváth et al. (2014), who show that these factors very often follow trends observed in emerging economies and international bond markets. Jabłecki, Raczko and Wesołowski (2016) employ the ACM term structure model for Poland and provide supporting evidence for a substantial decline in the term premium on 10-year bonds, which dips into negative territory after 2014. They explain these changes by the search-for-yield behaviour of foreign investors. Using an estimated DSGE model, Wesołowski (2018) presents the outcomes of a term structure decomposition and shows that term premium shocks have a significant impact on GDP in Poland, but their role in driving inflation is limited. In a recent contribution, Dec (2021) provides a detailed investigation into the Polish sovereign bond market taking into account its limited liquidity and discusses specific properties of this market.

## 3. Government bonds yield curve data

In this paper, we focus on sovereign bonds, securities that are issued by respective central governments and remain comparable in terms of their risk properties. In an optimal setting, we would prefer to use a yield-curve dataset containing zero-coupon government bond price with as many maturities as possible, corresponding, for instance, to the acclaimed US database developed by Gürkaynak, Sack and Wright (2007) and maintained by the New York Fed. However, given the limited accessibility of such series, this study uses a dataset that consists of benchmark bond yields, following the practice of Albagli et al. (2019). The time series for each CE economy include securities with up to six maturities. For Czechia, they consist of 2, 3, 4, 5, and 10-year bonds, since data on 1-year bonds for this economy are not available until January 2009. Hungarian government bonds comprise those of 6 months, 1, 3, 5, and 10-year maturities. In this case, the time-series on 2-year bonds were not fully available and were swapped for the 6-month rate. Interest-rate series that we use for Poland have maturities of 1, 2, 3, 4, 5, and 10 years. Additionally, we include Germany as a benchmark case throughout the analysis, given the importance of this economy for CE countries. The dataset of German sovereign bonds ranges from 1 to 10 years. Data are obtained from Refinitiv Datastream.

Throughout the study, we use monthly frequency data, defined as the observation on the last trading day of the month, ranging from June 2001 to December 2019. All of the interest rates were firstly converted into continuously compounded rates. For each economy, the yield curve was fitted using the Nelson-Siegel-Svensson (NSS) framework (Svensson, 1994). Next, the estimated NSS parameters were used to retrieve yield curves for maturities from 1 to 120 months, which subsequently served as an input to the ACM term structure model. The yield curves that we obtain for each economy (not reported here) are generally upward-sloping. It must be noted, however, that their slope is inverted for the initial years of the analysis, especially in Hungary and to some extent in Poland, most likely due to the ongoing disinflation that still took place in these economies during that period, along with high and variable short-term rates. Toward the end of the sample, there are clear signs of the yield flattening, similar to the phenomena observed in the advanced economies (Joslin, Priebsch and Singleton, 2014).

## 4. An outline of the ACM affine term structure model

There are several leading approaches to separate various components of bond yields (see a comprehensive review by Rebonato, 2018). The essential decomposition breaks them down into two chunks, the expected short-term interest rate and a time-varying term premium, requested by an investor to compensate for an additional risk of holding a security for an extended period of time. However, given that bond components are not observable and depend on the relationship between yields on assets of different maturities, we need a term structure model to capture the underlying factors driving bond yields. The modern workhorse of the macro-financial literature that serves this purpose is a (Gaussian) affine term structure model. This class of models is based on the assumption that observed yields and their expectation components can be expressed as affine functions of several risk factors, which summarise the term structure of interest rates and possibly other economic or financial variables. Interestingly enough, even though there is no uniform methodology to conceptualize and estimate such models, competing approaches largely concur on trends and dynamics of long-term interest rate components in the US and the euro area, as shown by Cohen, Hördahl and Xia (2018).

An important example of the dynamic term structure model was introduced by ACM. It is a computationally efficient and parsimonious technique to build a series of linear regressions and estimate pricing factors, which, in turn, are used to retrieve ex-ante neutral rates and term premia for various maturities of bonds. The ACM model is based on the notion that arbitrage opportunities are absent in the bond market. Under no-arbitrage, the pricing kernel $M_t$ is defined through risk-adjusted future pay-offs generated by an asset:

$$P_t^{(n)} = E_t \left[ M_{t+1} P_{t+1}^{(n-1)} \right] \tag{1}$$

where $P_t^{(n)}$ is a price of a security (bond) with maturity of $n$. In order to approximate the prices of risk, $K = 5$ principal factors (i.e. risk factors) are extracted from demeaned yields. This practice goes back to the work of Litterman and Scheinkman (1991), where the first three factors are intuitively interpreted as level, slope, and curvature of the yield curve. The factors are assumed to follow a VAR(1) process:

$$X_{t+1} = \mu + \Phi X_t + v_{t+1} \tag{2}$$

with normally distributed shocks to the state variables, $v_{t+1} \sim N(0, \Sigma)$. The stochastic discount factor, on the other hand, is expressed using $r_t$, the continuously compounded risk-free rate, and the price of risk, given by $\lambda_t$:

$$M_{t+1} = \exp(-r_t - \frac{1}{2}\lambda_t' \lambda_t - \lambda_t' \Sigma^{-1/2} v_{t+1}) \tag{3}$$

What is important in this type of model is that the price of risk is assumed to have an affine form, as in an influential work by Duffee (2002):

$$\lambda_t = \Sigma^{-1/2}(\lambda_0 + \lambda_1 X_t), \tag{4}$$

while ex-ante excess returns for a given yield of maturity $n$ are given by:

$$rx_{t+1}^{(n-1)} = \ln P_{t+1}^{(n-1)} - \ln P_t^{(n)} - r_t, \qquad n = 2, \ldots, N, \tag{5}$$

with $r_t$ also defined as an affine function of risk factors, $r_t = \delta_0 + \delta_1 X_t$.

The major contribution of ACM comes with a conceptual approach to the estimation procedure of $\lambda_t$ based on factors in $X_t$ and innovations to the VAR process. This procedure consists of three steps. In the first step, the VAR system from Equation (2) is estimated by OLS. Residuals are collected in matrix $\hat{V}$, and the variance-covariance matrix is calculated as $\hat{\Sigma} = \hat{V}\hat{V}'/T$.

The second step starts by stacking the excess returns for all maturities and periods in an $N \times T$ matrix $rx$. Here, based on the fitted NSS curve, the $n = 1$ month yield is taken as a risk-free rate ($r_t$) of the model, and excess returns are calculated for $N = 12$ maturities of $n = 6, 12, 18, \ldots, 60, 84, 120$ months. In this stage, the ACM approach makes use of the basic assumption that eventually allows us to retrieve the neutral rate and term premium. Namely, it states that the excess returns may be decomposed into four parts: (a) expected return, (b) convexity adjustment, (c) priced return innovation, and (d) return pricing error. Hence, using a form stacked across maturities and time, it is indicated to run the following regression:

$$rx = \alpha + \beta' V + cX_{-} + E, \tag{6}$$

where $\alpha$ is a constant, $V$ contains contemporaneous innovations to the VAR, and $X_{-}$ denotes lagged factors. Next, the error variance is calculated as $\hat{\sigma}^2 = tr(\hat{E}\hat{E}'/NT)$, based on an $N \times T$ matrix of errors, $\hat{E}$.

In the third step of the procedure, we use the outcome we obtained so far and calculate the market prices of risk from Equation (4). The first of them is given as:

$$\hat{\lambda}_0 = (\hat{\beta}\hat{\beta}')^{-1}\hat{\beta}\left(\hat{a} + \frac{1}{2}\left(\hat{B}^* vec(\hat{\Sigma}) + \hat{\sigma}^2\right)\right), \tag{7}$$

where $\hat{B}^* = [vec(\beta^{(1)}\beta^{(1')}) \ldots vec(\beta^{(N)}\beta^{(N')})]$ is an $N \times K^2$ matrix. Each of its elements $\beta^{(n)}$ come from a $K \times N$ matrix $\hat{\beta}$ (the matrix contains coefficients on $\hat{V}$ in Equation (6) for a given maturity $n$). The second price of risk is derived as:

$$\hat{\lambda}_1 = (\hat{\beta}\hat{\beta}')^{-1}\hat{\beta}\hat{c}. \tag{8}$$

Finally, once $\hat{\lambda}_0$ and $\hat{\lambda}_1$ are estimated, we retrieve the sovereign yield curve in a recursive way. This part of the modelling strategy follows a general rule applied in affine term structure models to perform yield decomposition (Rebonato, 2018). Each bond yield is expressed again as an affine process, $\hat{y}_t(n) = -\frac{1}{n}(A_n + B_n' X_t)$, and we denote factor loadings for excess returns as $\hat{\beta}^{(n)} = B_n'$. Altogether the system takes the form of two recursions and two initial conditions:

$$A_n = A_{n-1}' + B_{n-1}'(\mu - \lambda_0) + \frac{1}{2}(B_{n-1}'\Sigma B_{n-1}') - \lambda_0, \tag{9a}$$

$$B_n' = B_{n-1}'(\Phi - \lambda_1) - \delta_1', \tag{9b}$$

$$A_0 = 0, \quad B_0 = 0. \tag{9c}$$

The risk-neutral component, i.e. the expected short-term interest rate, is extracted by setting both market prices of risk $\lambda_t$ to zero, because it is best described as a yield that does not include any compensation for risk. The term premium component, in turn, is defined as a difference between the bond yield implied by the model and the neutral rate:

$$y_t^P(n) = \hat{y}_t(n) - y_t^N(n). \tag{10}$$

As we aim at studying in detail only the decomposition of 10-year bond yields, we denote $y_t^P(120) = y_t^P$ and $y_t^N(120) = y_t^N$ in the remainder of the paper. It must be highlighted here that $y_t^P$ may be treated in a sense broader than mere term premium (duration or interest-rate risk), as it gathers deviation from the neutral rate that may originate from various financial and economic shocks, such as shifts in consumption growth or inflation. Additionally, we calculate a long- and short-term interest rate spread that approximates the yield curve slope, $y_t^S$, based on the difference between the observed 10-year and 2-year bond yields (1-year rate for Hungary). We use the term spread as a simple reference point for our term premium estimates.

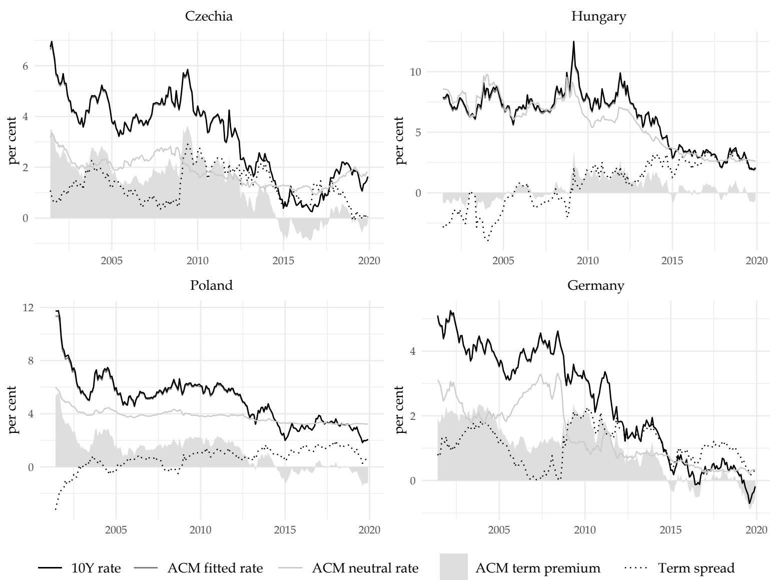
## 5. Empirical results

This section presents empirical results of the study. First, we explore the outcome of the estimated pricing models and examine changes in sovereign bond yields using the resulting decompositions. Next, we investigate international comovement in long-term rate components, both among the CE economies and between each of them and Germany. Finally, as a robustness check, we consider the bias-corrected outcomes of the ACM model.

### 5.1. Term premium and risk-neutral rate measures

The actual and fitted 10-year treasury bond yields, along with their components in all three CE economies and Germany, are depicted in Figure 1. It must first be noted that the ACM models produce a high-quality fit to 10-year yields. The series of actual and fitted yields are almost identical, which indicates small errors relative to the values of the modelled interest rates, just as in the ACM study on the US data. Starting with the estimates of the risk-natural rates, we observe notable differences in these components among the three CE economies. In Hungary, the neutral rate was considerably higher, especially in the 2000s, and more variable than in Czechia and Poland. A significant downward movement that began in 2009-2010 brought this rate in Hungary from around 9% in 2009 to 3% in 2015. Conversely, the initial neutral rate in Czechia was relatively low throughout the entire timespan. The country experienced a noticeable decline in this component between June 2008 and September 2013 (from 2.77% to 1.20%), but the neutral rate increased again post-2017. In Poland, the most prominent feature is the flattening of the neutral rate series in the latter part of the sample. After a decline from around 6% in the early 2000s, it quickly hit a plateau of around 4% in 2005, and by a slow downward movement it reached 3.22% in December 2019. Finally, the German neutral rate moved between 2% and 3% before the crisis. It approached 0.55% in March 2013, going down from the highest value of 3.31% in June 2008.

Term premia, the differences between actual and neutral rates, exhibit similar patterns in Czechia and Poland. First, the average value of this component throughout 2001-2019 was equal to 1.84% in the former economy, and 1.71% in the latter. The term premium in Poland, however, generally made up to a much smaller fraction of the 10-year yield. For example, in January 2006 the premium was equal to around 24% of the actual rate in this economy, while in Czechia this fraction stood at ca. 39%. Second, around 2008-2009 there was a clear upswing in premia in both economies (although a more pronounced one in Czechia), which may be understood as an increase in compensation for risk of holding Czech and Polish 10-year bonds during the onset of the financial and economic crisis. The same is true for Germany in this period. The term premium remained relatively high and positive in Czechia and Poland until 2012 when it started declining rapidly. In Poland, it hit zero in July 2014, and in Czechia a month later. From 2015 to 2019, its mean values were negative. Spreads between 10-year and 2-year bonds were generally lower than the term premium before 2013 and higher afterwards. There are some periods, such as 2008-2009 and 2014-2015, when the term spread moved in the same direction as the model-implied term premium.



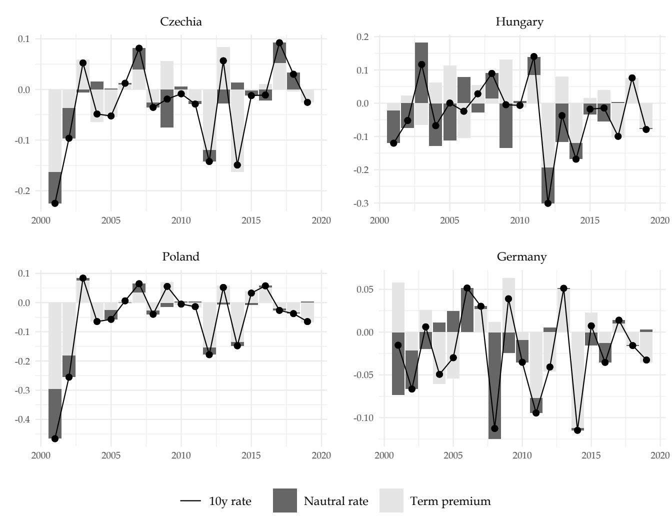

*Notes:* risk-neutral rates and term premia estimated in the ACM term structure model; term spread calculated as a difference between 10-year and 2-year bond yields.

**Figure 1.** 10-year sovereign yields and their risk-neutral and term premium components

Due to generally high natural rates, the picture is different for Hungary. Up to 2010, the behaviour of the ACM term premium and the term spread was quite unlike in Poland or Czechia. The expected path of short term rates in Hungary was higher than the 10-year yield for most of the period from 2001 to 2009. Therefore, the term premium in this economy remained predominantly negative, going as low as -1.5% in 2003, which must be considered an anomaly. It may be a consequence of the fact that the sovereign yield curve in this economy was inverted for a relativity long period, compared to Czechia and Poland. In Czechia, this phenomenon did not occur, while in Poland, it was only detected at the very beginning of the sample. In models re-estimated using yield series covering the post-2003 period, when inflation rates in CE economies further declined, the behaviour of term premia is highly comparable to the baseline estimates for all economies (those results are available upon request). The connections between term premium and observed rates in Hungary became more similar to that in Czechia and Poland from 2009 onwards. The term premium hiked to roughly 2.5% in 2008-2009, and then, around 2014-2015, it significantly declined, reaching very low and negative values in the last five years of the analysis.

### 5.2. Changes in long-term yields and their components

To get a closer look into long-term yields dynamics in CE economies, we first obtain month-to-month differences in long-term interest rates and their components. We next graph average annualised changes in 10-year yields, decomposed into risk-neutral rates and term premia (Figure 2). This decomposition indicates that in Czechia and Poland, changes in actual yields revealed a stronger connection to term premium dynamics. Most of the time, term premia were also decisive for the direction in which the 10-year rates moved in a given year. In fact, large swings in those yields in Czechia and Poland, such as ones observed between 2012 and 2014, were driven specifically by term premia. On the other hand, the role of the neutral rates was more pronounced for Hungary and it became less evident only post-2014. What seems distinct for Hungary among the CE economies, but also for Germany before 2010, is that there were numerous periods when changes in both components had inverse signs. For example, throughout 2002-2007 the risk-neutral rate and term premium dragged Hungarian 10-year rate in opposite directions, largely offsetting their individual contributions to the actual bond yield.




*Notes*: annualised dynamics calculated as average monthly changes in respective rates and their components during a given year.

**Figure 2.** Decomposition of annual changes in the 10-year sovereign yields

The variance shares of respective 10-year yield components, calculated as in Moench (2018), supplement our previous observations (Table 1). In Czechia and Poland, the ratio of changes in neutral rates to 10-year rates $(\Delta y_t^N, \Delta y_t)$ in the entire sample equalled 12.82% and 15.16%, respectively. This ratio decreased in the second subsample (2009-2019), and for Czechia it went as low as 4.78%. At the same time, the variance shares of term premium $\Delta y_t^P$ in $\Delta y_t$ increased, and this component became a visibly stronger driver of interest rates. In Czechia, the term premium variance shares were larger than the corresponding value for neutral rate by the factor of 19.5, and in Poland by 11.5. However, the most evident shift is observed for Hungary, where the variance ratio for term premium boosted from 21.86% to 77.60%. The variance shares of the term spread in sovereign bond yields $(\Delta y_t^S, \Delta y_t)$ were comparatively lower than their term premium counterparts. This ratio was highest for Hungary in the second subperiod but generally low in the Polish bond market, which speaks to the disconnect of those two series, especially before 2009. Post-2009, when the term spread shares categorically increased, their behaviour confirms a stronger impact of risk premia on bond yields.

**Table 1.** Changes in 10-year yields and their components: variance shares and correlations

| | | Variance shares | | | Correlations | | |
|---|---|---|---|---|---|---|---|
| | | $\Delta y_t^N, \Delta y_t$ | $\Delta y_t^P, \Delta y_t$ | $\Delta y_t^S, \Delta y_t$ | $\Delta y_t^N, \Delta y_t^P$ | $\Delta y_t^N, \Delta y_t^S$ | $\Delta y_t^P, \Delta y_t^S$ |
| 2001-2019 | Czechia | 0.1282 | 0.8527 | 0.4739 | -0.0850 | -0.5501*** | 0.7937*** |
| | Hungary | 0.4112 | 0.5784 | 0.3611 | -0.0159 | -0.4177*** | 0.8846*** |
| | Poland | 0.1516 | 0.8208 | 0.1651 | 0.5069*** | -0.2878*** | 0.3826*** |
| | Germany | 0.3168 | 0.6754 | 0.3074 | -0.0684 | -0.5103*** | 0.8149*** |
| 2001-2008 | Czechia | 0.2843 | 0.6914 | 0.1457 | 0.2684** | -0.5063*** | 0.5574*** |
| | Hungary | 0.7599 | 0.2186 | -0.2027 | -0.2347** | -0.7011*** | 0.8231*** |
| | Poland | 0.1959 | 0.7658 | -0.0368 | 0.6769*** | -0.3877*** | 0.0613 |
| | Germany | 0.5404 | 0.4461 | -0.0140 | -0.1329 | -0.6932*** | 0.7245*** |
| 2009-2019 | Czechia | 0.0478 | 0.9362 | 0.6421 | -0.2217** | -0.5483*** | 0.8638*** |
| | Hungary | 0.2220 | 0.7760 | 0.6735 | 0.1572* | -0.0459 | 0.9563*** |
| | Poland | 0.0792 | 0.9126 | 0.4894 | 0.2639*** | -0.0771 | 0.7241*** |
| | Germany | 0.1675 | 0.8263 | 0.5150 | 0.0414 | -0.2156** | 0.8862*** |

*Notes:* 10-year yields variance shares of the ACM natural rate, term premium, and 10-year over 2-year spread are given as $\frac{Cov(\Delta y_t, \Delta y_t^N)}{Var(\Delta y_t)}$, $\frac{Cov(\Delta y_t, \Delta TP)}{Var(\Delta y_t)}$, and $\frac{Cov(\Delta y_t, \Delta y_t^S)}{Var(\Delta y_t)}$, respectively; ***, **, and * indicate significance of Pearson linear correlation coefficient estimates at the 0.1, 0.05, and 0.01 levels, respectively.

As we turn to correlations of long-term interest rates components, it must first be noted that in the entire sample coefficients calculated between changes in estimated risk-neutral rates and term premia $(\Delta y_t^N, \Delta y_t^P)$ are statistically significant only for Poland. In this case, the term premium was typically decreasing while the neutral rate was also going down. However, the opposite regularity of negative correlation between $(\Delta y_t^N$ and $\Delta y_t^P)$ entails in Hungary in the first subsample and in Czechia post-2009. Neutral rates and yield spreads $(\Delta y_t^N, \Delta y_t^S)$ were generally inversely correlated, even though this correlation is not strong. Negative correlations indicate in this case that downward shifts in the neutral rate were connected to an increase in the slope of sovereign yield curves. Term premia and term spreads $(\Delta y_t^P, \Delta y_t^S)$ mostly changed in the same direction. This relationship, however, was weaker pre-2009, for all economies but most notably for Poland.

### 5.3. International comovements in long-term interest rates

In order to investigate international linkages in long-term yields, we first calculate average cross-country differences in 10-year yields and their components pre- and post-2009

(Table 2). The two-sided t-tests for differences in means indicate an interesting relationship. Distances in actual bond yields between the CE economies remain almost the same in two subsamples, with statistically insignificant differences in mean values. In Czechia, the 10-year rate was on average ca. 3 points lower than in Hungary and ca. 1.9 points lower than in Poland, while Hungarian yields were around 1.1 point higher than Polish ones. At the same time, Hungary reduced its distance to Czechia and Poland both when it comes to the neutral rate and the term premium. On the other hand, for Czechia and Poland, the differences in term premium components vis-à-vis Germany decreased, but the distance between the neutral rates significantly widened. For the Hungary-Germany pair, the opposite was true.

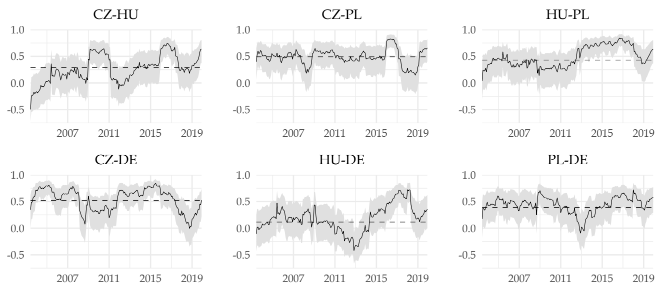
**Table 2.** Mean values of differences in 10-year bond yields and their components

| | | $y_t$ | $y_t^N$ | $y_t^P$ | $y_t^S$ |
|---|---|---|---|---|---|
| | 2001-2008 | -3.0078 | -5.1967 | 2.2842 | 2.3090 |
| Czechia - Hungary | 2009-2019 | -3.0995 | -3.0048 | -0.0303 | -0.7084 |
| | t-test | 0.5333 | 0.0000 | 0.0000 | 0.0000 |
| | 2001-2008 | -1.9189 | -1.8369 | -0.0072 | 1.1753 |
| Czechia - Poland | 2009-2019 | -1.8600 | -2.0258 | 0.1944 | 0.2499 |
| | t-test | 0.5859 | 0.0000 | 0.0076 | 0.0000 |
| | 2001-2008 | 0.3463 | -0.0738 | 0.4015 | 0.1710 |
| Czechia - Germany | 2009-2019 | 0.9730 | 0.7956 | 0.1618 | 0.1421 |
| | t-test | 0.0000 | 0.0000 | 0.0000 | 0.5506 |
| | 2001-2008 | 1.0889 | 3.3598 | -2.2913 | -1.1337 |
| Hungary - Poland | 2009-2019 | 1.2395 | 0.9791 | 0.2247 | 0.9583 |
| | t-test | 0.4289 | 0.0000 | 0.0000 | 0.0000 |
| | 2001-2008 | 3.3541 | 5.1228 | -1.8827 | -2.1380 |
| Hungary - Germany | 2009-2019 | 4.0725 | 3.8004 | 0.1922 | 0.8505 |
| | t-test | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 2001-2008 | 2.2652 | 1.7630 | 0.4086 | -1.0043 |
| Poland - Germany | 2009-2019 | 2.8330 | 2.8214 | -0.0326 | -0.1078 |
| | t-test | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

*Notes:* $y_t$, $y_t^N$, $y_t^P$, and $y_t^S$ denote country differences in average values of actual 10-year sovereign rates, neutral rate, term premium, and term spread, respectively; p-values of the two-sided t-test; null hypothesis: mean values are equal between subsamples.

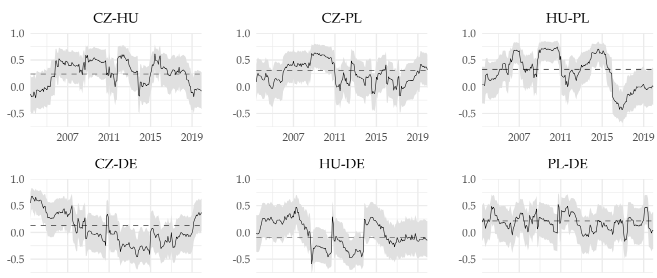
Next, we analyse correlations in bond yields and their components among countries. The rolling correlations that we obtain for changes in the term premia differ substantially, both across pairs of countries and in time (Figure 3). The correlation coefficient between Czechia and Poland was positive, fairly stable (in the whole sample: 0.49), and predominantly significant in the rolling window of 24 months. In pairs Czechia-Hungary and Hungary-Poland, we observe an upward trend in point estimates of the coefficient. In the former case, however, its values were on average smaller and increased in two periods: 2009-2011 and 2016-2017. The whole-sample correlation in term premia was comparably high and significant for Czechia-Germany (0.52) and Poland-Germany (0.39). In both cases, the coefficient declined around the global financial crisis (GFC), although visibly earlier for Czechia (around 2009) than for Poland (around 2011). Above all, developments in those correlations are consistent with comovements in 10-year yields. For Hungary-Germany, the correlation was hardly significant (in the whole sample, p-value of 0.089), and the confidence band included zero right up to 2013-2015 when it moved into positive territory where is stayed until 2018.

Figure 4 summarizes correlations of monthly changes in risk-neutral rates. In general, when it comes to correlations among the CE economies, the estimates are notably lower than the previously reported values and range from 0.24 (Czechia-Hungary) to 0.33 (Poland-Hungary; both p-values of 0.00). The rolling correlations became larger from 2005 to 2010 (Czechia-Hungary and Czechia-Poland), and from 2013 to 2015, with a brief period of significantly negative values around 2015-2016 (Hungary-Poland). Corresponding correlation coefficients with Germany were considerably smaller. In the entire sample, the point estimate of the coefficient was highest for Poland (0.21, p-value 0.00), lower for Czechia (0.13, p-value 0.06), and close to zero for Hungary. Additionally, there was a clear negative trend in the rolling correlations for Czechia-Germany and Hungary-Germany pairs, at least until 2013-2014.




*Notes:* correlation calculated using month-to-month differences in term premia estimated in the ACM term structure model; solid line: point estimates of rolling correlation coefficient (window equal to 24 months); shaded area: 90-percent confidence interval; dotted line: correlation coefficient calculated for the entire timespan.

**Figure 3.** Cross-country correlations: changes in term premia



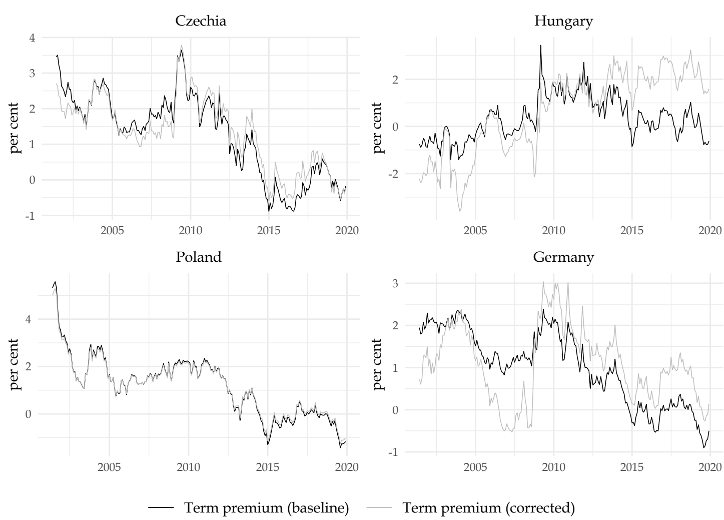

*Notes:* correlation calculated using month-to-month differences in risk-neutral rates estimated in the ACM term structure model; see Figure 3.

**Figure 4.** Cross-country correlations: changes in risk-neutral rates

### 5.4. Bias-corrected estimates

In the baseline ACM term structure model, the variables used to retrieve risk-neutral rates are derived from principal components of bond yield series. These components, in turn, are assumed to jointly follow an auto-regressive process given in Equation (2). However, as documented by Bauer and Hamilton (2012), such a VAR model estimated on a set of interest rates may be subject to small-sample bias. This bias is mainly related to high persistence – in our case, a downward trend – in interest rate series used to extract risk factors. In consequence, the baseline procedure may overestimate the term premium components and, equivalently, underestimate changes in neutral rates in the underlying bond yields. To ease this problem, we employ the stationarity adjustment correction for VAR models developed by Kilian (1998). In a nutshell, this procedure aims at eliminating unit or explosive roots in auto-regressive models by discarding the estimated models that reveal such characteristics. Based on this approach, we estimate the bias-corrected ACM model using 10000 bootstrap replications. Resulting term premium estimates are depicted in Figure 5.

Noticeably, in the Polish case, the term premium series (and risk-neutral rates) obtained from the bias-corrected model turn out to be almost identical to the one from the baseline model. The bias-correction, however, has an impact on the decomposition of long-term rates for all remaining economies. There are two main differences with respect to the initial models. First, risk-neutral rates become somewhat lower and more variable for Czechia, Hungary, and Germany, especially after 2009. On average, they decrease by 0.3 points for Czechia, and by 1.1 points for Hungary. Interestingly, the negative values that we obtain for Germany from 2015 are now more consistent with the evidence on the natural rate of interest in the euro area presented by Holston, Laubach and Williams (2017). Second, the term premium estimates are generally lower pre-2009 and higher afterwards. Even though they are not necessarily negative after 2013, they still reach comparably low levels in Czechia and Germany, and their general tendencies are unchanged relative to the baseline estimates. In Hungary post-2013, the term premium fluctuates as much as 1.5 points above the baseline outcomes.




*Notes:* term premia estimated in the ACM term structure model; bias correction based on Kilian (1998) with bootstrap using 10000 replications.

**Figure 5.** Model-implied term premium series: baseline and bias-corrected estimates

Next, we inspect whether the correction of the ACM model substantially influences the results on the international comovement in long-term interest rates (Table 3). As expected, the role of term premia diminishes in the corrected model at the expense of neutral rates. However, correlations in term premia remain visibly more important than comovements in neutral rates for Czechia-Poland, Czechia-Germany, and Poland-Germany pairs. Corresponding correlations between Hungary and Germany are even weaker than in the baseline model. Correlations in pairs Hungary-Poland and Czechia-Hungary stay on similar levels when it comes to the neutral rate, but are now lower for the term premium, again speaking for a distinctive character of the Hungarian sovereign bond market. In sum, however, these results suggest that our baseline estimates are subject to uncertainty, but the common patterns in their comovements identified before remain uninterrupted.

**Table 3.** Cross-country correlations between the risk-neutral and term premia components: baseline vs. bias-corrected ACM model

| | Baseline | | Bias-corrected | |
|---|---|---|---|---|
| | $\Delta y_t^N$ | $\Delta y_t^P$ | $\Delta y_t^N$ | $\Delta y_t^P$ |
| Czechia - Hungary | 0.2368*** | 0.2892*** | 0.2320*** | 0.1606** |
| Czechia - Poland | 0.3006*** | 0.4920*** | 0.2821*** | 0.4156*** |
| Czechia - Germany | 0.1288* | 0.5215*** | 0.1332** | 0.3493*** |
| Hungary - Poland | 0.3255*** | 0.4297*** | 0.3412*** | 0.2341*** |
| Hungary - Germany | -0.0904 | 0.1145* | -0.1059 | 0.0400 |
| Poland - Germany | 0.2138*** | 0.3898*** | 0.1520** | 0.2658*** |

*Notes:* see Table 1.

## 6. Discussion

Based on the empirical results reported in the previous section, this part of the paper discusses our major findings. In the first place, our results signify the role played by term premium components in the cross-border transmission of changes in long-term sovereign rates. For all three CE economies, we show that a higher dependence of bond yields on changes in term premia led the way to a more substantial influence of foreign factors on domestic bond markets. This pattern was evident for Czechia and Poland, which supports Kolasa and Wesołowski (2020), who demonstrate that in the Polish case, quantitative easing policies in advanced economies generated large effects for domestic sovereign bond markets precisely via term premia. In the case of Hungary, the situation seems to be more complex, as the country differs from Czechia and Poland when it comes to international interdependencies in the long-term interest rates. A plausible explanation of such differences comes from this country's higher idiosyncratic risk. Orłowski and Tsibulina (2014), for example, attribute Hungary's relative financial disintegration with the euro area to its weaker macroeconomic fundamentals. There is, however, an indication of convergence in term premium behaviour between Hungary and two remaining CE economies post-2012.

The role of the neutral rate as a driver of 10-year yields dynamics between the CE economies and Germany proved to be of secondary importance in the period of 2001-2019. It is worth noting that from around 2013, the decline of term premium in Germany coincided with a negative trend in the risk-neutral rate in this economy. On the contrary, in Poland, the neutral rate remained flat, and in Czechia it even increased in the last three years of the analysis. Consequently, as of 2019, the actual 10-year rates in Czechia, Hungary, and

Poland still stood 1.82, 2.27, and 2.25 points higher than German ones, respectively. The differences in risk-neutral rates equalled 1.46, 2.23, and 2.89. If we agree that the yields on German *bunds* are the lower-end reference point of bond yields in the European Union, the way for the 10-year bonds in the CE economies to converge to the core euro area levels must involve a reduction in the expected path of short-term interest rates. In this regard, the monetary response of the CE central banks to the COVID-19-induced crisis may contribute to a decrease in the risk-neutral component of bond yields in these economies, but this warrants further research in the area.

The finding that the behaviour of long-term sovereign rates in the CE countries became more reliant on factors other than the expected path of short term rates has important policy implications. On the one hand, it indicates that between 2009 and 2019 monetary policies in the CE economies were generally tighter and more passive than in the EMU, which accounts for sluggish changes in the neutral rates. On the other hand, it may also imply a limited impact of domestic monetary policy in these economies on the longer end of the yield curve through changes in term premia. What is more, it has been shown that as term premium components decline, they tend to become more sensitive to sudden decompressions, especially when they take unusually low values or fall below zero (Kopp and Williams, 2018). An exogenous negative shock may boost risk premia by altering inflation expectations, an outlook on future growth, or investors' sentiments, and have an eventual impact on monetary and macroeconomic conditions in CE economies.

In a broader sense, our results highlight the importance of international financial factors for the CE economies, and related susceptibility to shocks that originate in larger economies (Rey, 2016). It is not the same as saying that central banks in CE economies are entirely powerless in influencing long-term interest rates. However, in small economies with open bond markets, this impact seems to be limited, especially following the GFC. Even though Czechia, Hungary, and Poland avoided large spikes in 10-year yields during the taper tantrum episode of 2013, the interdependencies we identify tend to increase their exposure to sudden term premium shifts. For example, inflationary pressures or high levels of public debt may force investors to demand higher premium on long-term bonds. Conversely, we do not find much evidence that would lend support to the widely discussed secular stagnation hypothesis (Eggertsson, Mehrotra and Summers, 2016). As far as the 10-year sovereign yields go, the role of neutral rate in spreading a decline in interest rates to CE economies was relatively small, to begin with, and it diminished after the GFC.

## 7. Conclusions

Long-term interest rates rank among the most important financial and macroeconomic benchmarks, both from a domestic and international point of view. This paper aimed to examine the sovereign 10-year bond yields in three Central European economies, Czechia, Hungary, and Poland, from 2001 to 2019. We employed the ACM term structure to extract time-varying risk-neutral and term premium components of bond yields. We discussed the evolution of these components, along with their relative role in driving the actual interest rates. In the next steps, we studied international comovements of 10-year yields between the CE economies and Germany. As an extension, we corrected the baseline term structure model for a small sample bias.

In summary, three main points stand out. First, we find that Czechia and Poland, on the one hand, and Hungary, on the other, exhibited different patterns of sovereign long-term interest rates decomposition before 2009. Hungary experienced elevated neutral rates (the expected path of short-term interest rates), while Poland and Czechia relatively high term premia. Post-2009, both risk-neutral and term premium components declined substantially in all three CE economies. In particular, term premia were considerably compressed and approached zero (Hungary) and negative values (Czechia and Poland) around 2013, driving 10-year yields to historically low levels.

Second, we demonstrate that term premia played a larger role in the dynamics of 10-year interest rates in all three CE economies throughout 2001-2019. After 2009, their contribution was even more pronounced. Shifts in term premia explained around 90% of changes in long-term rates in Czechia and Poland, and over 80% in Hungary. At the same time, the role of the risk-neutral rates widely diminished. This phenomenon resembles tendencies observed in the last decade in the major advanced economies.

Third, we show that the 10-year rates in CE economies were higher than in Germany due to relatively larger values of risk-neutral rates, rather than term premium components. Cross-country correlations in 10-year yields were driven mostly by changes in term premia, and Czechia and Poland exhibited stronger ties with each other and with Germany. Hungary's connection to other economies was generally feeble but increased post-2012. Additionally, we demonstrate that the bias-corrected term structure models often produce higher estimates of term premia and lower neutral rates, especially in the second part of the sample.

A major limitation of this study comes from the fact that it relies solely on information embedded in the term structure of benchmark sovereign yields. In subsequent research, the results may be enhanced by using different interest-rate datasets and extending the study to include the COVID-19 period, e.g. by investigating the impact of non-standard monetary policies implemented in CE economies on long-term bond yields (Rebucci, Hartley and Jimenez, 2021). Also, it may be the case that macroeconomic risk factors, which could help in obtaining more precise estimates of risk premia, are "unspanned" by the yield curve (Joslin, Priebsch and Singleton, 2014). Some of those predictors may be directly included in yield curve modelling to expand our understanding of long-term interest rates in CE economies. As such, the results provided in this paper may serve as a useful yardstick for future work in this area.

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