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Systemic turbulence and risk spillovers in IBOR rates in Europe

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Abstract

Aim: The aim of the study was to investigate whether all European IBOR rates were similarly susceptible to turbulence as LIBOR rates, and also to analyse systemic risk spillovers between different IBOR rates in Europe and between these rates and the studied banking systems between 2006 and 2022.

Methodology: The interbank market turbulence measure (ITM) and ΔCoVaR were applied to analyse immediate spillovers based on coefficient analysis and rank the markets based on turbulence characteristics. Dynamic time warping (DTW) was used to cluster the analysed markets based on the course of turbulence, showing variable and time-changing commonalities in IBOR turbulence.

Results: Different levels of overall systemic turbulence for different groups of IBOR rates and in different periods were observed, along with the evidence of dissimilarity and minimal spillovers between LIBOR and IBOR rates after 2011. No evidence was found of risk spillovers from the interbank market towards the banking sector, only the inverse spillovers in the emerging markets were confirmed.

Implications and recommendations: The study shows that that there was no systemic-risk related reason for the CEE region to abandon the IBOR rates. The empirical results put the challenges, risks, and feasibility of a full transition toward the new rates in Europe in a new context. The conclusions are relevant for market regulators in the investigated region because they apply not only to the IBOR rates but also to the new rates adopted recently.

Originality/value: The paper presents a novel turbulence measure (ITM), developing and employing a set of innovations in calculating ΔCoVaR, as well as the DTW method developed for natural sciences in a financial market setting. Thanks to these methodological innovations the study encompassed an unprecedentedly large sample of countries, including 72 banks that are systemically important for Europe and 19 IBOR term structures, making this paper the most comprehensive analysis of Western, Central, and Eastern Europe with respect to interbank market turbulence.

Keywords: IBOR rates, interbank markets, systemic turbulence, risk spillovers

1 Introduction

In 2022 leading central banks in Europe – the Bank of England (BoE), the European Central Bank (ECB), and the Swiss Central Bank – together with the Financial Conduct Authority (FCA), Financial Stability Board (FSB), the US Federal Reserve and the Central Bank of Japan, intensified work on the initiative to retreat from the London Interbank Offered Rate (LIBOR) and to switch to alternative reference rates. To that effect, FCA (2021) declared that it would discontinue compelling banks to publish LIBOR rates beyond 2021. These events prompted other European markets to also look for alternatives. So far, this challenge has been faced with variable success, and many markets still do not have definitive answers to the upcoming transition.

In theory, the alternative reference rates should be risk-free. They should also align with the financial benchmark rate standards of the International Organization of Securities Commission (2018), developed in response to the turmoil related to the unethical fixings of LIBOR. However, the reality of the transition has shown that setting a new standard rate is problematic for many European markets — especially in the CEE countries that are generally less liquid — and that transaction-based continuous rates with sufficiently large volumes are difficult to establish. Yet, the literature does not provide any thorough scientific studies addressing the pros and cons of the transition in a research-informed systematic framework with relation to emerging and frontier markets. This creates a significant research gap.

Building on the conclusions formulated in Eross et al. (2016), Hernando-Veciana and Tröge (2020), Fabrizi et al. (2021), and Pontines and Rummel (2023), this paper fills that gap investigating whether all European IBOR rates are similarly susceptible to turbulence as LIBOR based on two hypotheses. Hypothesis 1 postulates that the susceptibility of IBOR rates to systemic turbulence is time-varying and different for advanced and emerging markets, while Hypothesis 2 states that systemic turbulence present in the IBOR quota spills over from the interbank market into the larger banking sector.

The analysis introduces a novel risk measure that captures systemic risk-related turbulence in interbank market rates. This measure forms the foundation for identifying turbulence patterns across LIBOR- and IBOR-based markets and for comparing their dynamics. The study also applies cluster analysis, using dynamic time warping (DTW) with several targeted modifications. The evaluation of turbulence intensity across different subperiods relies on statistical ranking techniques. Further sections explore systemic risk spillovers among European IBOR rates and between these rates and national banking systems, using purpose-designed statistical instruments. The discussion connects empirical findings to broader questions surrounding the risks, challenges, and viability of a full benchmark rate transition in the CEE region.

It is important to point out that systemic risk measures proposed in the literature are not directly applicable to most systemically important banks in emerging markets and smaller developed countries, which greatly limits the scope of any existing analyses related to Europe. To address this constraint, the paper introduces a novel method for measuring interbank market turbulence and calculating ΔCoVaR. This framework supports the examination of an unprecedentedly large sample comprising 72 systemically important banks in Europe and 19 IBOR term structures, covering 33 European countries from Western, Central, and Eastern Europe, including 16 emerging and frontier markets.

The analysis indicates that there is a significant difference in susceptibility of LIBOR, EURIBOR and other IBORs to systemic turbulence. Empirical evidence suggests that much of that susceptibility was reduced after the scandals, and the remaining turbulence has rational and fundamental reasons. At the same time, the paper confirms the presence of spillover effects; however, their direction contrasts with expectations based on previously published research on LIBOR rates.

These conclusions are relevant for market regulators in the investigated region because they apply not only to the IBOR rates retrospectively, but also to the new rates currently being adopted. That is because an empirical study of these rates and their reactions to systemic risk and risk spillovers is not possible before the actual application occurs. At the same time, the predictive value of any simulation-based analyses is limited by the large scope of uncertainty regarding the future shape of the interbank markets in emerging European countries.

The layout is as follows. The paper opens with an overview of the literature in two main areas relevant to the empirical analysis. The discussion focuses on systemic risk, including its transmission and amplification mechanisms related to systemic illiquidity and risk spillovers. The next section explores interbank markets and IBOR rates in the context of systemic turbulence and inefficiencies. This is followed by a presentation of the hypotheses, applied models, data, and empirical findings. The final section outlines the implications of the results and offers a follow-up discussion.

2 Literature review

2.1 Systemic risk and the role of illiquidity in systemic turbulence

Systemic risk can be defined as the “breakdown of the entire system rather than simply the failure of individual parts” that takes the shape of “a cascading failure in the financial sector caused by linkages within the financial system” (CFA, 2022), and has “negative spillover effects on the real economy” (Brownlees, & Engle 2017, p. 50). As such it is a product of bank-specific and market-specific characteristics. The first group refers to the internal characteristics of systemically important banks that make them more or less likely to be affected by external shocks, and to propagate them. The other category refers to all factors that make the markets in which these banks operate more likely to generate and propagate such shocks themselves (cf. Silva et al., 2017).

At the same time, systemic risk is a product of processes that materialise in three dimensions: illiquidity, fragility, and interconnectedness. Therefore, this risk may be analysed in terms of accumulation and amplification (Benoit et al., 2017) that characterise banks and markets both separately and conjointly. Importantly, when these dimensions overlap, systemic risk materialises. Empirical studies show that at such moments systems freeze, banks fail, and the shocks propagate outside the banking sector affecting the real economy.

Systemic turbulence and liquidity are very closely related. Importantly, market liquidity may be fragile if structurally undiversified, even if otherwise ample (IMF, 2015, pp. 49-87). Simultaneously, low liquidity can be volatile and is prone to sudden drops. In such instances, prices become less informative, move away from fundamentals, and increase market volatility. Such a mechanism may work in closed loops, amplifying systemic risk. In extreme circumstances, this type of turbulence leads to systemic outcomes, such as market freezes.

Market liquidity is likely to be resilient when frictions are small. This includes efficient and transparent market infrastructure, easy access to funding, low search and transaction costs, and a risk appetite that promotes active market participation. Such factors ensure that smaller frictions do not build up to a systemic scale and amplify. In uncollateralised markets these characteristics evaporate suddenly when turbulence affects them (Duffie, 2014; Chen, & Duffie, 2021). Under these conditions, the most amplified frictions include information asymmetry, communication breakdowns, and uncertainty about the counterparty's creditworthiness. They lead to substantial market illiquidity, despite high funding liquidity – and – because financial systems are networks these illiquidity effects are self-reinforcing (Buiter, 2008).

Several amplification mechanisms are important for systemic risk events related to illiquidity. For instance, Bessembinder et al. (2011) demonstrated that benign cyclical conditions can disguise liquidity risks, making them difficult to identify before systemic consequences materialise. Clementi (2001) argued that cycle-driven market liquidity promotes excessive risk-taking, leading to the build-up of fragilities. Similarly, Geanakoplos (2010) showed that it drives unsustainable leveraging, negatively affecting the overall stability of the financial system.

Studies show that periods of excessive liquidity amplify behavioural biases and lead to systemic fragilities. For instance, overconfidence leads to trading frenzies in markets that are very liquid (Scheinkman, & Xiong, 2003). This, in turn, promotes asset price bubbles and the build-up of leverage. The global financial crisis showed how this mechanism manifests (Brunnermeier, 2008). Similarly, the COVID-19 crisis revealed the scale of pre-pandemic leverage build-ups, when the interest rates were unprecedentedly low (Duffie, 2020; Vivar et al., 2020; Vassallo et al., 2020).

The literature describes illiquidity-related effects leading to amplifications and systemic risk in four categories: illiquidity exposures in the banking sector (Brunnermeier, & Oehmke, 2013; Lubiński, 2013), illiquidity-driven contagions in the financial markets (Shleifer, & Vishny, 1992; Brunnermeier, & Pedersen, 2009; Cespa, & Foucault 2014), illiquidity-driven crises (Shleifer, & Vishny, 1997; Gromb, & Vayanos, 2002; Cifuentes et al., 2005; Diamond, & Rajan, 2005; Brunnermeier et al., 2013; Brunnermeier, & Sannikov, 2014), and interbank market freezes (Flannery, 1996; Caballero, & Simsek, 2013; Acharya et al., 2011; Gorton, & Ordonez, 2014; Heider et al., 2015).

The empirical studies of these four types of systemic phenomena were conveyed by, among others, Coval and Stafford (2007), Aragon and Strahan (2009), Boyson, Stahel and Stulz (2010), and Morris and Shin (2012). More recently, Schrimpf et al. (2020) studied the after-effects of the leverage spiral that amplified systemic illiquidity during the COVID-19 pandemic. A similar analysis can be found in the ECB's *Financial Stability Review* (2020).

Interbank markets have a special role in systemic risk propagation and amplification (cf. Boss et al., 2004, Nier et al., 2008, Drehman, & Tarashev, 2011, Gofman, 2015). Allen and Gale (2000a) found that the interbank markets' susceptibility to liquidity shocks depends on their structure. Elsinger et al. (2006) related the default probabilities to the interbank market knock-on effects. Afonso, Kovner, and Schoar (2011) reported that interbank loans in the United States became more sensitive to borrower characteristics during the global financial crisis. The findings from the UK's interbank market (Acharya, & Merrouche, 2013) and the Eurosystem (Gabrieli, & Co-Pierre, 2014) brought evidence of liquidity hoarding, following the predictions of the theoretical model by Allen, Carletti, and Gale (2009). Hernando-Veciana and Tröge (2020) postulated that in times of financial stress, only 'coarse' equilibria survive, in which interbank submissions only partially reveal the bank's true borrowing rate. Among the more recent studies, Dziwok and Karaś (2021) and Karahan and Soykök (2023) reported that systemic illiquidity materialised in all three turbulent periods in various European countries, including Central and Eastern Europe and Turkey.

2.2 Systemic risk spillovers

Risk spillovers are a common consequence of illiquidity-driven systemic turbulence. They suggest that "the instability of the given institution (instrument, market, infrastructure, financial system sector) will spread to other parts of the financial system with negative effects, leading to a system-wide crisis" (Smaga, 2014, p. 11). Typically, they result from interdependence – a connectedness with a defined source and direction of impact – between financial system participants. Contagion effects are characterised by a defined transmission mechanism that is unexplainable by economic fundamentals, caused by negative extremes, and sequential. Thus, risk spillover translates the micro-scale risks affecting single institutions into a system-wide effect.

Connectedness, correlation, and contagion were recognised as the key aspects of systemic risk (Scott, 2012). Most studied channels of systemic risk spillovers include the liquidity and information channels described in the previous section, as well as the balance sheet channel, especially the mutual credit risk exposures (Benoit et al., 2017) and the structural one, related to high concentrations (Cifuentes et al., 2005; OFR, 2015) and – in more recent papers – to market fragmentation (Pala, 2024; Chen, & Duffie, 2021).

Financial systems are prone to transmitting shocks as they are built from interconnected elements. For Acharya (2009), the "joint failure risk" arising from the correlation of banks' assets is crucial for risk spillover. However, his approach shows that it is not necessary to use data that represent direct exposures (e.g. ownership data, loan exposures, or portfolio compositions) to capture the links between banks (Acharya, & Rajan, 2024). As long as there is a clear transmission mechanism with identified risk spillover channels, such a spillover may be identified using observations related to the co-occurrence of risk (Brownless, & Engle, 2017; Adrian, & Brunnermeier, 2017).

Various theoretical papers discussed risk spillovers in the context of interbank markets. Allen and Babus (2009) and Allen et al. (2012) found that the network effect amplifies risk spillovers, while Allen and Gale (2000b) and Freixas et al. (2000) proved that network completeness decreases fragility. At the same time, too dense interconnections (Gai, & Kapadia, 2010; Acemoglu et al., 2015) and specifically shaped networks (Castiglionesi, & Navarro, 2011; Anand et al., 2013; Babus, & Hu, 2017; Farboodi, 2023; Babus, 2016) serve as a mechanism for the propagation of shocks. Empirical papers identifying these phenomena include Chan-Lau et al. (2009), Markose et al. (2012), Elliott et al. (2014) and Upper and Worms (2004).

Interestingly, Eisenberg and Noe (2001) and Leitner (2005) demonstrated that some banks voluntarily expose themselves to risk spillovers. Zawadowski (2013) showed that unhedged counterparty risk in the interbank markets may lead to bank runs, while Afonso and Shin (2011), Duffie and Zhu (2011), Koeppl, Monnet and Temzelides (2012), Acharya and Bisin (2014) and Duffie (2014) all argued that central counterparties could be effective in preventing illiquidity spillovers, which in a broader sense also applies to interbank market exposures.

Unfortunately, none of the cited studies analysed the markets in the CEE region leaving an important research gap. This paper addresses that gap by examining the co-occurrence of turbulence in interbank market-based IBOR rates and immediate risk spillovers into the European banking system over the last twenty years.

2.3 Interbank market, its risk exposures and IBOR-rates failings

Since a well-functioning interbank market is crucial for redistributing liquid assets and effective monetary policy transmission (Schmitz, 2011), central banks are interested in maintaining a strong linkage[1] between their operating targets and interbank lending rates. Moreover, interbank market-

[1] The weakening of this link affects monetary policy signal transmission pass-through. It is one of the reasons why central banks created extraordinary liquidity and credit facilities during several recent financial crises.

based yield term structures are important because they contain information about the forward rates. In fact, Interbank Offered Rates (IBOR rates) could be called “the world’s most important number” (Vaughan, & Finch, 2017) linked to transactions with a notional amount of more than $370 trillion (AFME, 2019) after an extremely fast growth of derivatives markets in the 2000s, when the volume of LIBOR-linked instruments grew tenfold from $10 trillion to $100 trillion in the United States alone (JP Morgan, 2019).

Before the global financial crisis, banks were systematically replacing government-guaranteed instruments with wholesale loans and deposits from the interbank money market which led to unprecedented risk exposures of the banking systems. For instance, by 2006, interbank loans of Swiss banks composed almost 30% of their assets, whilst for German banks this was 25% (Upper, 2011). The Lehman Brothers collapse catalysed this process. After the global financial crisis, interbank assets were five or more times bigger than the equity for many systemically important European banks. In effect, interbank markets became a strong contagion channel for systemic risk in the aftermath of the crisis.

This trend reversed around 2014, after the introduction of the new regulations aimed at addressing the fragility of the financial system related to leverage and illiquidity of systemically important banks (Burgess, 2020, p. 7). With the Basel III reform, this change gained pace. However, Brexit (Acharya, & Thakor, 2016; Danielsson et al., 2017; Engle, & Zazzara; 2018, Dao et al., 2019) and the recent crisis related to the COVID-19 pandemic showed that systemic risk did not disappear from the interbank markets (Acharya, & Steffen, 2020; EBA, 2020; Covi, & Gu, 2022; Wang et al., 2023; Qi et al., 2022).

This is not surprising, given that interbank loans are only partially covered by the macroprudential regulations, which is especially problematic when groups of banks are concerned. To make matters worse, they are completely missing from the sections about over-exposure and concentration. Thus, the resulting mutual exposure of banks may directly lead to risk spillovers, especially in the face of market fragmentation that prevails during the crises (Blåvarg, & Nimander, 2002; Duffie, & Stein, 2015; Pala, 2024).

The London Interbank Offered Rate (LIBOR) was introduced as a measure of uniformity for the interbank market, and over the last thirty years it became the global benchmark and reference rate used to price a broad variety of loans and derivatives with a wide range of maturities. After the establishment of LIBOR as the reference rate, many interbank benchmarks similar to LIBOR have been established in different financial markets worldwide, including Europe (see Table A2 in Appendix). EURIBOR became the most popular reference rate alongside LIBOR, while many countries using national currencies developed similar rates for their local markets.

Importantly, there exist many differences between how these rates are set relative to LIBOR, and much of this variability appeared as a regulatory response to the LIBOR rate crisis in 2012 described earlier. For instance, ROBOR (Romania), CIBOR (Denmark), and NIBOR (Norway) were to be set under the financial market regulator. On the other hand, Croatia decided to discontinue its ZIBOR rate and not apply it to the new EU requirements. Another particularly crucial characteristic is that the rates are fixed based on local systemically important bank (O-SIIs) submission panels. Denmark, for instance, excluded global banks involved in the scandals from its panels (Aagaard, 2012).

LIBOR rates have been criticised for a variety of characteristics. Above all, there was always a significant disproportion between the nature of the rates and their impact on the financial system. Most interbank loans and deposits had maturity of one week or less, while almost all the transactions referencing LIBORs were historically related to significantly longer maturities. Nearly $200 trillion in contractual exposures referenced USD LIBOR in 2018, of which roughly 95% was the notional exposure under derivatives contracts, with only approximately $8 trillion in exposure under corporate loans, consumer debt (primarily mortgages), floating-rate notes, and securitized products (Kudenholdt, 2018).

The LIBOR rates were also criticised for being prone to distortions[2] "during periods of market stress when banks stop lending to each other across the full maturity spectrum, from overnight to one year" (Kliff, 2012, p. 33). This likely had its reason in the excessive leverage accumulating up to 2014, coupled with the non-resilient liquidity of the unsecured interbank funding markets. The global financial crisis revealed that LIBOR rates were more prone to turbulence than expected and could be easily affected by credit risk bubble build-ups.

The non-transactional nature[3] of these rates was another crucial problematic characteristic. LIBOR signals constituted only a likely interbank market and not the actual one. In turbulent periods, banks were likely to outdo one another to inflate their perceived creditworthiness, providing unrealistic rate values. An even more pressing problem related to conflicts of interest in which banks could profit from their pre-existing trading positions depending on the favourable fixings of LIBOR.

The method of fixing LIBOR became a source of problems with technological advancements, particularly in advanced financial markets, where the aforementioned conflicts of interest arose and gained importance. The problem became exacerbated by the small panel size (see Table A1 in Appendix), the ease of immediate communication, and the culture of networking and sharing information between banks when both were to benefit from it (e.g. corroborating submissions). What magnified the problem was that managers of banks were not required to ensure the robustness and quality of the quotes, while regulators had a limited ability to take disciplinary action.

Thus, it is no surprise that LIBOR has a stigmatised record due to a number of high-profile rate scandals related to manipulations by traders in 2012 that "undermined the confidence in the reliability and robustness of these interest rate benchmarks" (Kansal, & Melatur, 2020). By 2015 the fines for rigging LIBOR amounted to more than $9 billion, while regulators in the United States, the UK, and the European Union uncovered a profiteering plot by multiple banks. Among others, Barclays, Citigroup, Deutsche Bank, JP Morgan Chase, Rabobank, Royal Bank of Scotland, and UBS admitted to wrongdoings, with Deutsche Bank paying the highest fine of $3.5 billion – more than twice as much as any other institution (Freifeld, 2015). In effect, the LIBOR quotation failures and scandals necessitated the reform of the interbank rate quotation system (Duffie, & Stein, 2015).

Several papers suggested that banks submitted underestimated rates after the collapse of Bear Stearns investment bank in March 2008 and after Lehman Brothers' collapse half a year later (Abrantes-Metz et al., 2011a; Rauch et al., 2013), and that banks were not reporting accurately (Hou, & Skeie, 2014; Braml, 2016; Bariviera et al., 2016; Eisl et al., 2017; Pontines, & Rummel, 2023). McConnell (2013) argued that the scandal was a manifestation of systemic operational risk, while Fabrizi et al. (2021) demonstrated how the commonality of incentives and opportunity to commit fraud triggered a reputational contagion among systemically important banks in response to the LIBOR scandal. Nonetheless, the studies that looked for bank-specific signs of collusion were generally inconclusive or not specific (Atanasov et al., 2015, Ashton, & Christophers, 2015; Bahoo, 2020). There are no papers reporting on the issues of manipulation or collusion for other IBOR rates.

New Basel regulations and the European Union Benchmarks Regulation (Regulation EU/2016/1011…) diminished the utility of unsecured interbank borrowing and the size of LIBOR-based interbank exposures. Furthermore, in the last years there was a continuing push from the regulators to stop fixing LIBOR rates and to switch to alternative rates that are transaction-based and closer to the theoretical concept of the risk-free rate. Many researchers claimed that continuing with the LIBOR benchmark was not feasible based both on market trust (Bailey, 2019) and on practical considerations (Kuo et al.,

[2] LIBOR rates were fixed based on the non-transactional, subjective information – provided by a panel composed of a small number of systemically important banks that were being asked about the hypothetical acceptable cost of capital raised on an unsecured basis on a given day. Based on their answers, LIBOR was computed and published daily as the average of the submissions with the most extreme quotes removed.

[3] In one quoted instance, there were only 15 wholesale lending transactions throughout the year (Kansal, & Melatur, 2020). That made any submission impossible to corroborate in a robust manner.

2018; Indriawan et al., 2021). There was an expectation that it would be discontinued after 2021 when the Financial Conduct Authority withdrew from compelling banks to provide quotes.

Despite these voices and the regulatory reform being actively implemented, IBOR rates continued until June 2023, and the global market was sluggish to abandon them. In the meantime, various regulatory measures were implemented to improve the fixing procedures, minimise the bias in the rates themselves, and strengthen bank balance sheets[4]. As the LIBOR rate was embedded in financial system infrastructure and models for over three decades, its scale and scope of applications possibly made the switching from LIBOR to new alternative reference rates one of the largest undertakings the financial industry has ever faced. By 2024 many IBOR rates remained in the market, including the second largest reference rate, which is the EURIBOR rate.

3 Hypotheses and models

3.1 Research hypotheses

Several phenomena discussed in the previous section may apply to all interbank markets, potentially affecting all IBOR rates. This reasoning motivated the formulation of Hypotheses 1 and 2, which were examined using the empirical framework described in Section 5. The analysis proceeded without specific ex-ante expectations, given the absence of parallel studies in the literature addressing IBOR rates beyond LIBOR. These considerations gave rise to two hypotheses:

Hypothesis 1: Susceptibility of IBOR rates to systemic turbulence is time-varying and different for advanced and emerging markets.

Hypothesis 2: Systemic turbulence present in the IBOR quota spills over from the interbank market to the larger banking sector.

In relation to Hypothesis 1, it was particularly interesting to study if there were any contrasts between the LIBOR and other rates, and in a larger sense – between advanced and emerging markets. The other intention was to observe if there were any significant and systematic changes in the turbulence susceptibility of the rates over time, particularly in light of the macroprudential regulation and reforms implemented within the study period, and if these effects spilled over to the banking sector amplifying negative systemic risk effects (Hypothesis 2).

3.2 Measure of systemic illiquidity

Previous studies indicate that interbank markets are sensitive to noise-based metrics derived from parametric model-fitting procedures. Therefore, the measure proposed by Dziwok and Karaś (2021), when applied to IBOR rates across the analysed markets, captures turbulence. A comparable strategy appears in Duffie (2022). The analysis applied in this paper relies on the Nelson-Siegel (1987) model with Svensson’s (1995) extension.

Parametric models show five distinct empirical applications in the context of liquidity risk measurement. Hu et al. (2013) used the Svensson model on returns on hedge funds and currency carry trades data to create a measure of dispersion, i.e. a noise-type measure. The implied noise corresponding to the difference between the theoretical and empirical market yields is then applied as a liquidity risk factor in portfolio risk modelling. More recently, similar applications were proposed by Dziwok and Karas (2021), Hattori (2021), Duffie (2022), and Karahan and Soykök (2023) for the banking sector.

[4] That includes a new regulatory and governance framework as well as market-leading validation techniques: real-time and post-publication surveillance and tests to assess credibility of submissions and rates; new surveillance methodology that employs sophisticated analytical tools increasing transparency; the use of a new Secure File Transfer Protocol service (IBA, 2014).

The term structure of interest rates derived by using parametric models reacts to turbulence as the expectations of the market participants change. This is especially true for shorter maturities. The structure is affected by the changing expected liquidity and default risk premiums, risk aversion, and market participants' preferences. Moreover, it responds to central bank policy actions (cf. Lucas, 1978; Cox et al., 1981; Shiller, & McCulloch, 1990, Mehra, 1995). This makes it an essential source of information about market frictions that appear and dissipate in the banking system over time.

To apply these models to detect illiquidity-based systemic frictions in the IBOR rates, one needs to construct the yield curve for the moment in time τ, which implies that the value of a zero-coupon instrument at maturity equals $P_t(\tau,t)=1$, where t is maturity, and the capital growth is continuous. Then the spot rate may be described as the average of the instantaneous forward rates:

$$i(\tau,t)=\frac{1}{t-\tau}\int_{\tau}^{t} f_{\tau}(s)ds. \tag{1}$$

The value of the zero-coupon instrument at moment τ for $P_{\tau}(\tau,t)$ is equal to discount factor $\delta(\tau,t)$. It also follows the formula (de La Grandville, 2003):

$$P_{\tau}(\tau,t)=\delta(\tau,t)=e^{-i(\tau,t)\cdot(t-\tau)}=e^{-\int_{\tau}^{t} f_{\tau}(s)ds}. \tag{2}$$

When the moment of the rate construction is $\tau=0$, and assuming that

$$P_{\tau}(\tau,t)=P_0(0,t)\equiv P(t),\ \delta(\tau,t)=\delta(0,t)\equiv\delta(t),\ f_{\tau}(s)=f_0(s)\equiv f(s), \tag{3}$$

one may simplify equation (2) to:

$$P(t)=\delta(t)=e^{-i(0,t)\cdot t}=e^{-\int_0^t f(s)ds}. \tag{4}$$

Now, it is possible to model the yield curve by constructing a continuous function based on the actual discrete market data, using the relationship between the discount factor, the spot rate, and the instantaneous forward rate. Since discount factor $\delta(t)$, spot rate $i(0,t)$, and implied forward rate $f(s)$ are mutually unequivocally correspondent, it is only necessary to search for one of them (cf. James, & Weber, 2000).

The yield curve is constructed in four steps. First, for moment $\tau=0$ one selects a k-set of zero-coupon assets with different maturities whose present values are P_l for $l=1,2,\ldots,k$ and face value is one. In step two, one must construct a diagonal cash flow matrix $\boldsymbol{C}$ for collected zero-coupon data. Its elements correspond to payments. Next, the vector of theoretical prices $\overline{P_l}=\{P_l\}_{l=1,2,\ldots,k}$ needs to be described as the product of cash flow matrix $\boldsymbol{C}$ and the estimators of the interrelated discounting factors (see Equation 4):

$$\begin{bmatrix}\overline{P_1}\\ \overline{P_2}\\ \vdots\\ \overline{P_k}\end{bmatrix}=\boldsymbol{C}\cdot\left[\bar{\delta}(t_1),\bar{\delta}(t_2),\cdots,\bar{\delta}(t_k)\right]^T. \tag{5}$$

In step four, one fits the parameters by minimising mean square error (MSE) between theoretical and market data entries. This step involves either prices or yields that allow minimising function $\Psi(\cdot)$, such that

$$\Psi(P)=\sum_{l=1}^{k}(P_l-\overline{P_l})^2\rightarrow min \text{ or } \Psi(Y)=\sum_{l=1}^{k}(i_l-\overline{\iota_l})^2\rightarrow min. \tag{6}$$

Imposing a set of specified initial conditions during the estimation process on the parameter vector is crucial in this step. The Nelson-Siegel-Svensson model requires the estimation of six parameters: β_0, β_1, β_2, β_3, δ_1,δ_2, such that

$$f(s)=\beta_0+\beta_1\cdot e^{\frac{-s}{\delta_1}}+\beta_2\cdot\frac{s}{\delta_1}\cdot e^{\frac{-s}{\delta_1}}+\beta_3\cdot\frac{s}{\delta_2}\cdot e^{\frac{-s}{\delta_2}}. \tag{7}$$

Then, spot rate $i(0,t)$ takes the form:

$$i(0,t) = \beta_0 + (\beta_1 + \beta_2)\frac{1-e^{\frac{-t}{\delta_1}}}{\frac{t}{\delta_1}} - \beta_2 \cdot e^{\frac{-t}{\delta_1}} + \beta_3 \cdot \left(\frac{1-e^{\frac{-t}{\delta_2}}}{\frac{t}{\delta_2}} - e^{\frac{-t}{\delta_2}}\right). \tag{8}$$

For each day of the estimated term structure, the error value (i.e. the noise) is plotted on the time axis. Each such value reflects the degree of deviation between the theoretical and market rates and is interpreted as the interbank market turbulence measure (ITM) that signals frictions in the IBOR-based term structures.

3.3 Risk spillovers: ΔCoVaR measure

The ΔCoVaR model was applied to empirically analyse the spillover effects in the banking system. It is a quantile-based conditional measure drawing from the concept of Value at Risk. It measures the interconnectedness of the banking sector, computing how a banking sector index falls when an individual bank stock price declines based on the rate of return of the individual stock relative to the banking sector stock index. By plotting ΔCoVaR over time, one can analyse the soundness of the financial sector conditional on triggers (at least VaR-level losses) involving a certain bank, as well as the current conditions compared with those from the past.

In line with the above, ΔCoVaR captures the contribution of each systemically important bank to the overall systemic risk in a non-causal sense because it assumes the conditionality of individual bank risk on the distress of the financial system. However, this measure is focused on the spillover of risk between banks in response to a bank-external systemic risk trigger. Therefore the ΔCoVaR of a bank is its risk spillover potential. The estimation of ΔCoVaR starts from the financial system perspective.

To calculate the daily ΔCoVaR values for a comprehensive set of banks, this study introduces a novel approach that enables the construction of cross-border banking systems, reflecting the actual international presence of large banks in the analysed European markets. In such a framework, the banking system s is a combination of stock-exchange-listed systemically important banks i with weights w_i totalling to unity, where $i = 1, \ldots, N$. All the banks used in the empirical analysis were identified as systemically important (G-SIBs or O-SIIs) by financial market regulators (BoE, 2022; BoR, 2022; EBA, 2022; FINMA ,2022). For reference on the construction of each country's banking system and the Eurozone banking system, please refer to Table A3 in Appendix.

The rate of return at time t for bank i is denoted as $r_{i,t}$, and for banking system s as $r_{s,t}$. This rate of return equals:

$$r_{s,t} = \sum_{i=1}^{N} w_{i,t} \cdot r_{i,t}, \tag{9}$$

where $w_{i,t}$ is the weight of financial institution i in system s, is either based on its systemic importance score reported by the EBA (2022)[5] or market capitalisation. In both cases, it is equal to:

$$w_{i,t} = \frac{c_{i,t}}{\sum_{j=1}^{N} c_{j,t}}, \tag{10}$$

where $c_{i,t}$ is either the systemic importance score or market capitalisation of bank i in the given banking system s.

5 This method makes it possible to calculate the $\Delta CoVaR$ model for many emerging European countries for which the traditional capitalisation-based method makes it impossible to include the impact of risk spillovers generated by the majority of systemically important banks in the region. It has additional advantages that allow considering the true systemicness of each bank.

Then, the Value at Risk (VaR) of each financial institution i in the given financial system s at the level of confidence $(1-q)$ is equal to:

$$VaR_{i,t}^{q}(r_{i,t}) = inf\{r_{i,t}: F_i(r_{i,t}) \geq q\}, \tag{11}$$

where F_i is the cumulative distribution function of $r_{i,t}$. As $P(r_{i,t} \leq VaR_{i,t}^{q}) = q$, $VaR_{i,t}^{q}$ is determined as a q-quantile of distribution F_i, the VaR of an individual financial institution i is:

$$VaR_{i,t}^{q} = \sigma_{i,t} F_i^{-1}(q), \tag{12}$$

where $\sigma_{i,t}$ is the volatility of the rates of return at time t.

CoVaR of the financial system measures the total price of risk in the banking system conditional on each bank in distress. Formally, $CoVaR_{s,t}$ of the banking system s corresponds to the $VaR_{s,t}^{q}$ of the market return obtained conditionally on $VaR_{i,t}^{q}$ observed for bank i, where q is derived as:

$$q = P\left(r_{s,t} \leq CoVaR_{s,t}^{q|r_{i,t}<VaR_{i,t}^{q}} | r_{i,t} < VaR_{i,t}^{q}\right). \tag{13}$$

$\Delta CoVaR_{i,t}$ models the marginal contribution of each bank to overall systemic risk, capturing it in a non-causal sense. The distress threshold of bank i is defined as $VaR_{i,t}^{q}$ and distress equals every instance when losses are at least at the level of $VaR_{i,t}^{q}$:

$$\Delta CoVaR_{i,t}^{q} = CoVaR_{s,t}^{q|r_{i,t}VaR_{i,t}^{q}} - CoVaR_{s,t}^{q|r_{i,t}=Median(r_{i,t})}. \tag{14}$$

Following Jajuga et al. (2017), to build a system-wide time series reflecting the spillover effects captured by individual banks' $\Delta CoVaR$ values, portfolio-based aggregation is applied over the predefined set of systemically important financial institutions $i = 1,2,\ldots,N$:

$$\Delta CoVaR_{s,t}^{q} = \sum_{i=1}^{N} \left(\Delta CoVaR_{i,t}^{q} \cdot w_{i,t}\right). \tag{15}$$

Estimation

In accordance with the approach applied in Benoit et al. (2017), GARCH methodology guides model parameters' estimation. For conditional volatility the GJR-GARCH models were applied, and to model dynamic correlation the GARCH-DCC models were used (cf. V-Lab[6]), where r_t is the vector of $(r_{s,t}, r_{i,t})$ at time t, modelled as:

$$r_t = \sqrt{\boldsymbol{H}_t} \upsilon_t. \tag{16}$$

As indicated in equation (16), vector υ_t of independent and identically distributed random variables $(\varepsilon_{s,t}, \varepsilon_{i,t})$ was applied, for which $\mathbb{E}(\upsilon_t) = 0$ and $\mathbb{E}(\upsilon_t \upsilon_t') = \mathbb{I}_2$ is a 2×2 unit matrix. In effect, the conditional covariance matrix takes the form:

$$\boldsymbol{H}_t = \begin{pmatrix} \sigma_{s,t}^2 & \sigma_{i,t}\sigma_{s,t}\rho_{s,i,t} \\ \sigma_{i,t}\sigma_{s,t}\rho_{s,i,t} & \sigma_{i,t}^2 \end{pmatrix}, \tag{17}$$

where $\sigma_{s,t}$ is the conditional standard deviation of system s at time t, $\sigma_{i,t}$ is the conditional standard deviation of financial institution i at time t, and $\rho_{s,i,t}$ is the time-varying conditional correlation coefficient.

6 Volatility Lab reports the methodology of the applied GARCH models at: https://vlab.stern.nyu.edu/docs

Finally, $\Delta CoVaR$ was estimated as:

$$\Delta \widehat{CoVa}R^{q}_{i,t} = \rho_i \sigma_s \widehat{VaR}^{q}_{s,t}, \tag{18}$$

applying the Value at Risk of the banking system calculated based on the weighted average of returns of listed systemically important banks used to create each banking system model.

4 Data

The empirical data set consists of publicly available data on a versatile sample of 72 banks that are systemically important for 27 European advanced, emerging, and frontier financial markets, including Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, France, Germany, Greece, Hungary, Iceland, Italy, Latvia, Lithuania, Luxemburg, the Netherlands, Norway, Poland, Romania, Russia, Spain, Slovakia, Sweden, Switzerland, Ukraine, and the United Kingdom. The data encompasses the period from 2006 to 2022. There are approximately 230 000 entries of the analysed banks' stock prices and capitalizations, as well as approximately 415 000 entries regarding IBOR rates fixed for 19 different interbank markets, and more than 500 entries regarding systemic importance scores. For the banks associated with the EBA, the scores were obtained directly from the European Systemic Risk Board website (ERSB, 2022), from the Notification Letters section; for Switzerland from the financial regulator's website (FINMA, 2022), and for the United Kingdom and Russia from their central bank websites (BoE, 2021; BoR, 2022). The source of all data used in this paper is Refinitiv Eikon and DataStream.

The time scope of the analysis spans the years 2006 to 2022, which contain data from five turbulent periods: the global financial crisis, the rigging scandals coupled with the public debt crisis in Europe, the Brexit, the COVID-19 pandemic, and the war in Ukraine. The geographic scope of the study covers Western, Central, and Eastern European countries that reacted differently to each turbulence.

Despite some cross-border differences between how rates were being fixed (discussed before), the rates are generally comparable due to their forward-looking nature, embedded risk premiums, their functions in the financial markets, maturities, and the applicability of the parametric models. Many interesting characteristics may be observed for the term structures based on the different IBOR rates. Figures (B1 to B19) present the term structures depicting these characteristics in Appendix B, each for all available maturities.

The term structures depict several characteristics. Generally, the number of IBOR maturities varies from country to country and over time. Several maturities disappeared, and some are introduced. Four of the analysed countries entered the Eurozone in the study period, and the period of rate synchronisation includes significant rate decreases across time.

Some systematic traits can be identified for the turbulent periods. They include distortions of the term structure that relate to the shortest maturity when these rates spike above the other, longer-term rates. This is most noticeable during the global financial crisis. In some cases, e.g. in Croatia, the distortion relates to more than one maturity. For Romania, in October 2008, there were large distortions of the whole term structure with spiking reversals. In Poland and Norway, as in Ukraine, the shortest maturity spikes above the other maturities also appeared in the latter turbulent periods.

Similarly, spikes in the rates corresponded to turbulent periods. The highest levels appeared around the global financial crisis, but increases were also visible in the last period related to the Russian aggression on Ukraine. In this very recent period, observations were limited due to the discontinuation of some of the IBOR rates. For Russia, turbulence spikes also preceded the Crimea annexation period.

5 Empirical results

The overall aim of the empirical analysis is to investigate a latent characteristic that adheres to the following logic: if there were significant spillovers of turbulence between the LIBOR and IBOR rates in the analysed time period – then the course of the turbulence measure should have a significant level of commonality between various markets. Such a commonality may manifest in many different ways.

The analysis presented in the remainder of the paper focuses on common paths of the turbulence time series, with attention to cointegration and immediate spillovers captured through short-window correlations. Clustering of the studied markets follows from distance measures applied within subperiods using the DTW method, to identify relative similarity in turbulence across IBOR rates. Turbulence-based rankings provide a comparative perspective on overall turbulence characteristics across subperiods. To complement the analysis, the path of the illiquidity-based turbulence measure (ITM) appears alongside that of a systemic risk spillover indicator, $\Delta CoVaR$, to trace potential commonality and assess the extent to which turbulence in interbank markets spills over into broader financial systems, including a comparison between LIBOR rates and IBORs in European frontier markets.

5.1 Co-occurrence of turbulence in different interbank markets

Bearing in mind that spillovers of turbulence manifest themselves in clustering of volatilities, to investigate whether systemic turbulence spilled over between different IBOR rates in the study horizon, the ITM measure was computed for each IBOR rate, and then the moving coefficient of variation with separate, different orders of aggregation in relation to standard deviation and the arithmetic average were constructed. For its construction, $k_1 = 26$ was applied, corresponding to the approximate number of working days in a five-week period, and in relation to the average, $k_2 = 250$ was used, to capture the approximate number of working days in a year:

$$\varphi_t = \frac{\vartheta_{(t-k_1+1):t}}{\mu_{(t-k_2+1):t}}, \qquad (19)$$

where $\vartheta_{(t-k_1+1):t}$ is the standard deviation of the values of the ITM series from $t - k_1 + 1$ to t, and $\mu_{(t-k_2+1):t}$ is the average of the values of the ITM series with numbers from $t - k_2 + 1$ to t (i.e. a moving average of order k_2)[7].

Figures 1 to 4 present selected pairs of interbank markets, while the remaining results are provided in Appendix B (Figures B20–B28).

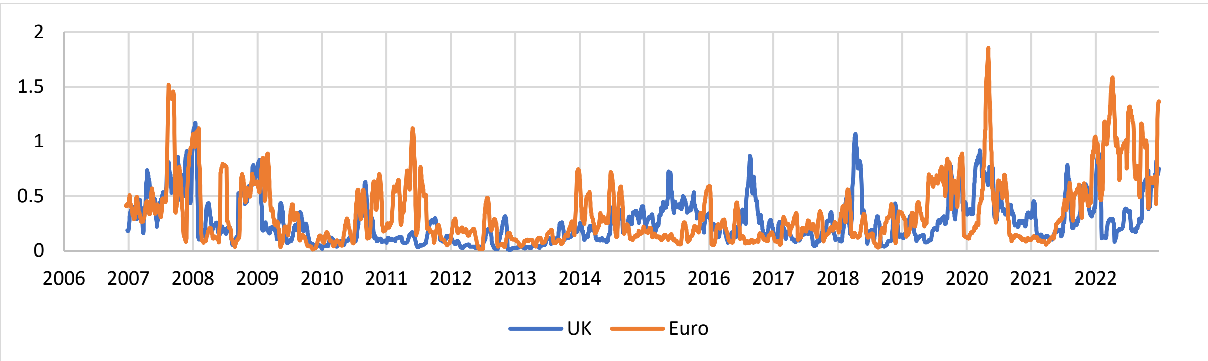


Fig. 1. Comparison of moving coefficients of variation of ITM – the United Kingdom vs. Eurozone

Source: Authors' calculations.

7 For robustness also shorter and longer windows for the moving coefficients were analysed.

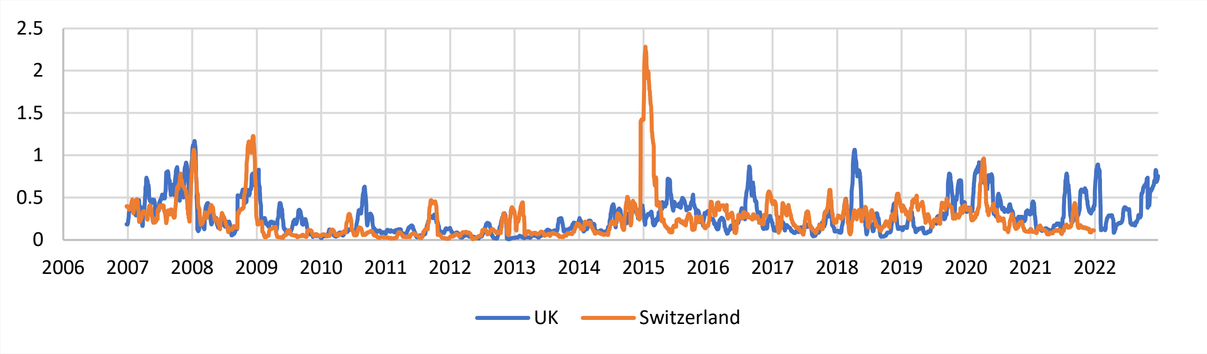


Fig. 2. Comparison of moving coefficients of variation of ITM – the United Kingdom vs. Switzerland

Source: Authors' calculations.

The results indicate the greatest similarity in the pairs formed for the interbank markets in the United Kingdom, Switzerland and the Eurozone. This similarity applies to turbulent periods, especially the global financial crisis and the COVID-19 pandemic. At the same time, specific, sporadic deviations regarding individual systems are visible: Eurozone – early 2014 and 2022 (the war in Ukraine), Switzerland – the turn of 2014/2015, the United Kingdom – around the time of Brexit, in 2016.

Despite the significant methodological differences between this and the earlier studies, and a much smaller scope of the previous papers, the results related to LIBOR rates presented here are in line with the literature. The few papers that successfully applied quantitative methods to prove that there was manipulation and turbulence in the LIBOR rates include the studies by Abrantes-Metz et al. (2011b) and Rauch et al. (2013), who used Benford's second-digit distribution to track the daily LIBOR over the period 2005 to 2008, as well as Bariviera et al. (2016), who applied the complexity-entropy causality plane to reveal the abnormal movement of the LIBOR time series around the period of the global financial crisis.

Pontines and Rummel (2023) – who used the Lasso linear regression technique - found that, when compared to the US short-term funding benchmarks, LIBORs showed the largest incidence of additive outliers. Similarly, Eisl et al. (2017) and Ganghi et al. (2019) analysed the bank level LIBOR and EURIBOR submissions and confirmed manipulations case by case up to 2011. Finally, Braml (2016), who examined the integrity of the LIBOR market using a three-pillar approach – interest rate parity, the construction of a theoretical LIBOR rate based on credit default swaps, and simulation techniques – confirmed market manipulation by systemically important banks between 2007 and 2011.

Figures 3 and 4 depict interbank market turbulence spillovers in other European markets. Interestingly, similarities between the Eurozone and Denmark are visible only during the global financial crisis and the recent period of war in Ukraine.

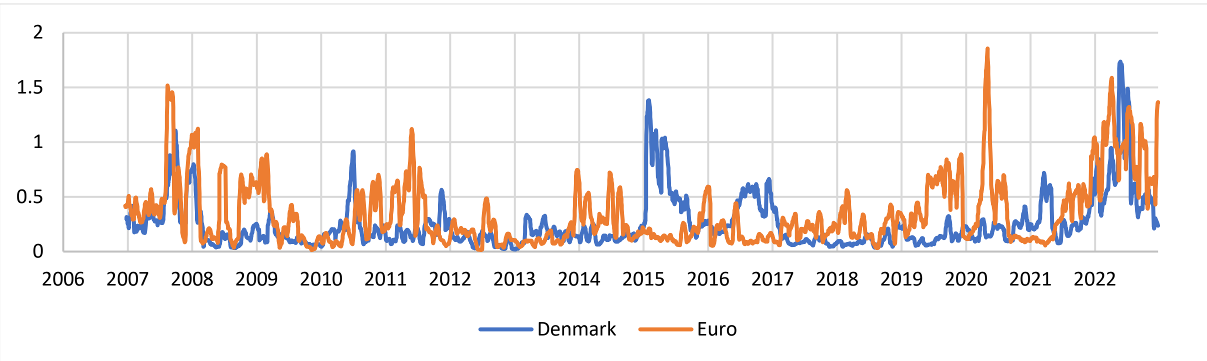


Fig. 3. Comparison of moving coefficients of variation of ITM – Denmark vs. Eurozone

Source: Authors' calculations.

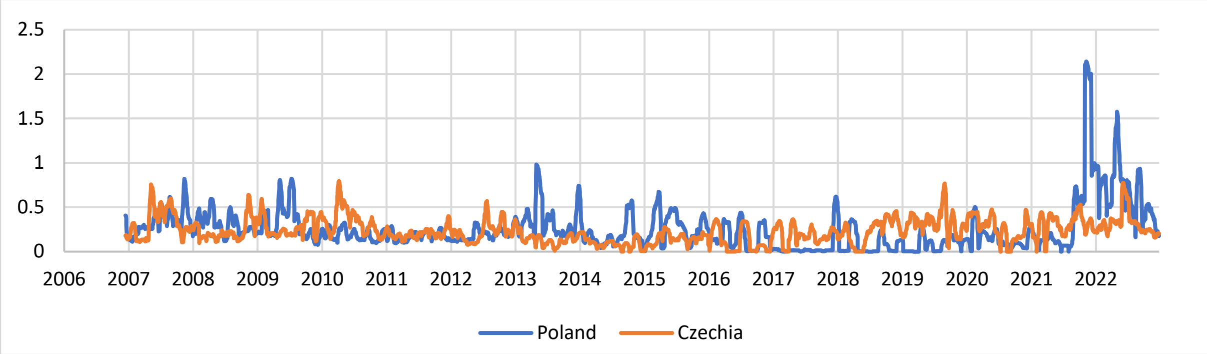


Fig. 4. Comparison of moving coefficients of variation of ITM – Poland vs. Czechia

Source: Authors' calculations.

Figures 3 and 4, as well as the ones presented in the Appendix show that other interbank markets also reacted to turbulent periods, but they did not follow very similar patterns, as the timing of their response to turbulence varied greatly. Different reactions were captured even for the countries that were similarly exposed to systemic risk (e.g. compare Czechia, Poland and Hungary). Such an observation is particularly visible in the most recent period that refers to the pandemic and the war. Also in the case of the countries that successively entered the Eurozone in the study period, before their accession, the interbank markets reacted in their own different and specific ways – this concerns, for example, Estonia and Slovakia.

In conclusion, the results indicate no evidence of systematic immediate spillovers of systemic turbulence that would apply to all the turbulent periods for the emerging markets. Commonalities were identified only for the LIBOR and EURIBOR rates.

Table 1. Spearman rank correlation coefficients

	Bulgaria	Croatia	Czechia	Denmark	Estonia	Euro	Hungary	Iceland	Latvia	Lithuania	Norway	Poland	Romania	Slovakia	Sweden	Switzerland	UK	Ukraine
Croatia	.19																	
Czechia	-.02	.38																
Denmark	-.09	-.03	.07															
Estonia	.08	.49	.38	-.02														
Euro	.11	.36	.30	-.03	.77													
Hungary	.04	.22	.16	.08	.12	.09												
Iceland	.15	.29	.19	.02	.22	.08	.06											
Latvia	.07	.58	.34	.03	.78	.62	.08	.33										
Lithuania	.20	.26	.19	-.05	.54	.59	.04	.01	.47									
Norway	.37	.08	.15	.00	.25	.45	.07	.01	.10	.20								
Poland	.16	.28	.30	.31	.40	.23	.13	.29	.38	.16	.13							
Romania	.18	.43	.23	.14	.31	.21	.12	.47	.39	.06	.17	.37						
Slovakia	-.11	.39	.32	-.02	.80	.87	.12	.08	.66	.52	.21	.23	.24					
Sweden	.17	-.02	.18	.21	.17	.27	.03	-.03	.07	.15	.52	.26	.04	.15				
Switzerland	.17	.35	.35	.04	.42	.36	.11	-.05	.34	.38	.40	.26	.01	.33	.26			
UK	.05	-.03	.04	.21	-.06	.08	-.07	-.06	-.09	.02	.30	.07	-.05	.06	.26	.19		
Ukraine	.26	.42	.21	-.08	.32	.25	.16	.38	.40	.02	.30	.24	.52	.26	.00	-.04	-.15	
Russia	.38	.04	-.05	-.15	.10	.17	.11	.07	.05	.11	.22	.04	.17	.11	.01	.10	-.03	.23

Caption: This table presents the Spearman rank correlation coefficients for the country-level analysis of ITM, where the red colour marks positive correlations and the blue colour indicates negative correlation, while the intensity of the colours corresponds in each case to the strength of the detected relationship.

Source: Authors' calculations.

To assess the robustness of the conclusions, the similarities between the ITM time series were further analysed. As a preliminary analysis, a simple method of comparison was applied to the pairs of interbank markets based on the correlation coefficients for the entire study period. For this purpose, two rank correlation coefficients (Spearman's and Kendall's) were computed for the pairs of the ITM series. The choice of coefficients was dictated by the fact that systemic turbulence time series are always characterised by sporadic big outliers. Hence, linear correlations are not to be expected.

The aim of this analysis was to capture immediate spillovers, understood as effects that, in principle, occur without any temporal lags. Such an analysis was strictly related to the instant reactions to systemic risk triggers captured by the ITMs in different markets. The results for the Spearman rank correlation coefficients are presented in Table 1, while for the Kendall tau coefficients, the results are shown in Appendix Table A4.

The correlation coefficients between the ITM time series vary for different pairs. The strongest refers to pairs among Slovakia, Latvia, Lithuania, Estonia, and the Eurozone (between approximately 0.7 and 0.9). However, their high correlation simply relates to the fact that these countries have one common Eurozone-based turbulence time series for a sizable part of the study period. In all other cases, the coefficients are objectively quite low, and it is impossible to confirm without a discriminatory analysis that any relation was captured by the correlation coefficients. Similarly as observed previously, there is no evidence of immediate turbulence spillover between the analysed markets, even those geographically close. No previous studies investigate these relations, hence no literature comparisons were possible.

5.2 Dynamic time warping, distance, and clustering

Since the ITM series of individual systems are not typical econometric empirical time series, their similarity can be measured in subperiods using the dynamic time warping (DTW) method (Keogh, & Ratanamahatana, 2005; Wieczorek et al., 2021). The similarity determined in this way preserves the chronology and, at the same time, flexibly takes into account shifts in the phase and amplitude of one series relative to the other. Moreover, the compared series need not be equal. The latter property is desirable since the individual systems, to some extent, are characterised by different days when IBOR rates are not quoted. Thanks to DTW, there is no need to delete data that do not have daily counterparts in the second series.

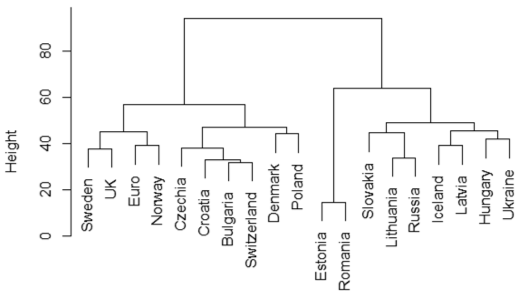
Comparing a pair of series follows the rules: (1) the first elements of both series and the last elements of both series must be paired, (2) each element of one series must be assigned with at least one element of the other series and vice versa, (3) pairing may not disturb the chronology in any of the series. The pairing of elements of both series minimises the cost of transition from one series to the other, which allows for determining the similarity between the pair of examined series (Sakoe, & Chiba, 1971; 1978; Petitjean et al., 2011).

Therefore, it is possible to use cluster analysis to study captured similarities. The essence of cluster analysis, its basic concepts, and the selected algorithms were described, among others, in Milligan and Cooper (1987), Gordon (1999), and Schubert (2017). This study applies a bottom-up type (agglomerative) hierarchical clustering analysis.

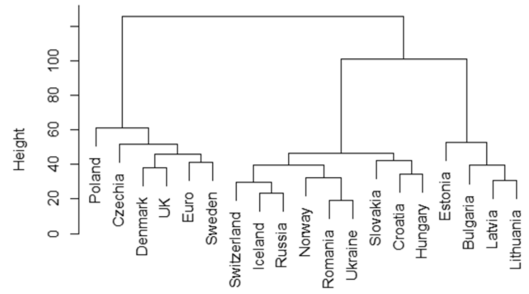
In the first step, each considered object (here: a series of ITMs within a fixed period) constitutes a separate group (cluster). In the next steps, the previously created groups of objects most similar to each other (closest to each other) are combined into larger groups. The procedure of building larger and larger groups continues until all objects are included in one group. It should be noted, however, that to calculate the distance between the connected groups, an additional rule must be adopted as to how this distance is understood. The clustering technique applied in this paper relies on Ward's method, which seeks to minimise the sum of squared deviations between any two clusters formed at each clustering step.

TSdist package in the R environment (cf. Hennig, 2015; Walesiak, & Dudek, 2016) was applied to determine the distances between the analysed markets. For each of the considered periods, the distance between each pair of ITM series was determined to measure the degree of their similarity (long distance equals small similarity, and short distance means high similarity). Clustering was also executed in the R environment – the TSclust package (Montero, & Vilar, 2014) was applied.

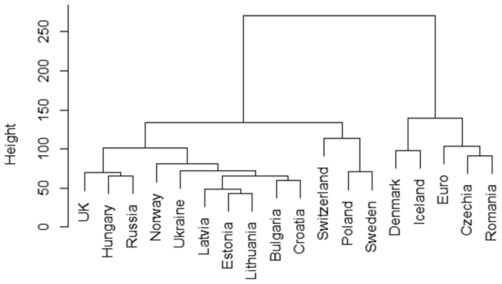
The cluster analysis results are presented in seven dendrograms (Dendrograms 1 to 7), each corresponding to a separate period. The dendrograms at their very bottom contain single objects, whilst in their upper parts they show the successive joining of groups into larger and larger groups.



Dendrogram 1. Period 1 (02.01.2006 –31.07.2007)
Source: Authors' calculations.

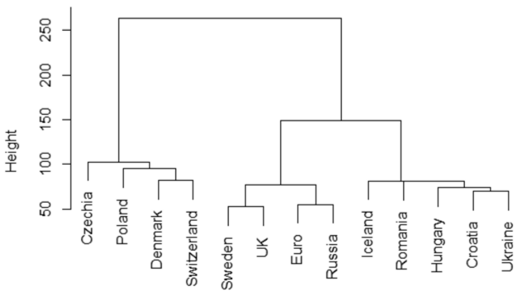


Dendrogram 2. Period 2 (01.08.2007 – 31.07.2009)
Source: Authors' calculations.

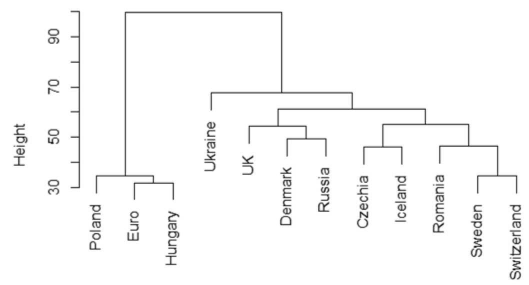


Dendrogram 3. Period 3 (03.08.2009 – 31.12.2013
Source: Authors' calculations.

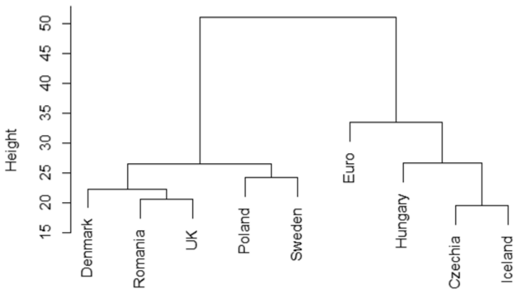
Dendrogram 4. Period 4 (01.01.2014 – 31.05.2016)
Source: Authors' calculations.



Dendrogram 5. Period 5 (01.06.2016 – 31.01.2020)
Source: Authors' calculations.



Dendrogram 6. Period 6 (03.02.2020 – 16.02.2022)
Source: Authors' calculations.



Dendrogram 7. Period 7 (17.02.2022 – 30.12.2022)
Source: Authors' calculations.

Several conclusions can be drawn based on the observations reported in Dendrograms 1 to 7. The height of the dendrograms indicates the distances between the markets and it depends on two factors: the size of the sample – a product of the number of the analysed markets and the length of the period under analysis, and on the actual diversity within the sample itself, corresponding to the actual differences between the analysed ITMs. The results indicate that the markets vary significantly from one another in all analysed subperiods and that the level of this difference remains relatively stable. These observations show that – when considered as one large sample – the analysed markets are not similar in terms of turbulence.

Furthermore, the DTW algorithm captures the differences between developing (emerging and frontier) and developed countries, grouping them separately. In more detail, markets with geopolitical commonality are grouped together. Examples include the Baltic countries in the first, second, and the third subperiod; and the groupings of Czechia with Poland and Ukraine with Russia throughout the analysis, except for the most turbulent third period. Interestingly, Russia groups inconsistently with different markets throughout the analysis, but this relates to the fact that different markets become the most turbulent ones in different subperiods – and Russia always groups with these markets. The relatively consistent groupings relate to developed countries, with different pairs formed between the UK, Switzerland, the Eurozone, and Sweden.

To sum up, based on the DTW algorithm, it appears that spillovers (robustly similar paths of the ITM measure) are visible between Baltic countries and between the Eurozone and the UK, but only before the LIBOR reform. One can also see very high variability and distinctiveness of the time series, which suggests that LIBOR rates turbulence did not systematically spill over across markets across different turbulent periods. Also in this case no previous studies exist, hence no literature comparisons were possible.

5.3 Comparative rankings based on the turbulence characteristics

A set of rankings was constructed to compare different interbank markets based on the IBOR rates turbulence. These rankings were created for the subperiods that correspond to distinct systemic turbulence events – the same ones as in the clustering analysis.

The rankings were based on a multicriterial analysis applying an aggregated score based on a collective evaluation of different analysed characteristics of the ITM measure output. Two classic measures of fit were adopted: the mean squared error (MSE) and the mean absolute error (MAE) – both of them were treated as destimulants. The criteria for seven subperiods were determined, and the markets were ranked in a descending scale. Thus, the rankings were based on the average level of turbulence, on the standard deviation of turbulence, and on both of these criteria considered together.

These three sets of rankings are generally robust. The exceptions include Czechia and Lithuania, whose ranks based on volatility (measured by standard deviation) were different from those based on the level of turbulence itself. For Czechia this was the case in four periods, and for Lithuania – in two periods. A similar observation relates to Iceland in period 3, and to the Eurozone in period 6. Otherwise the ranks are robust. The multicriterial ranking based on both standard deviations and average levels of ITM is shown below, while the other two rankings, prepared as robustness checks, are presented in Appendix for transparency.

Firstly, it should be emphasised that for all the analysed markets the level of turbulence subsided over time (see Appendices A and B). However, upon a closer look, one can see that for markets that were more turbulent in the initial subperiod (especially frontier markets), the calming effect was much stronger than in developed countries. This points to a certain degree of stabilisation of the former markets compared to the latter. This characteristic is captured in the rankings (see e.g. Poland, Czechia, Iceland).

Table 2. Ranking of markets based on level and volatility of turbulence in seven sub-periods

Period Country	02.01.2006 – 31.07.2007	01.08.2007 – 31.07.2009	03.08.2009 – 31.12.2013	01.01.2014 – 31.05.2016	01.06.2016 – 31.01.2020	03.02.2020 – 16.02.2022	17.02.2022 – 30.12.2022
Bulgaria	1	16	15	11			
Croatia	17	17	17	13	10		
Czechia	12	8	6	8	5	7	3
Denmark	7	1	3	5	3	2	4
Estonia	15	11	11				
Euro	6	5	4	4	1	9	6
Hungary	8	9	9	9	7	11	9
Iceland	13	12	13	10	9	3	2
Latvia	16	14	14				
Lithuania	5	6	8	3			
Norway	9	13	12				
Poland	10	7	7	7	4	1	5
Romania	19	15	16	14	11	4	7
Slovakia	14	10					
Sweden	2	4	5	6	8	5	8
Switzerland	3	3	1	2	2	8	
Ukraine	18	19	18	15	13	12	
UK	4	2	2	1	6	6	1
Russia	11	18	10	12	12	10	

Caption: This table presents the multicriterial rankings of markets based on the ITM level and ITM volatility in seven sub-periods, where the number and the intensity of the colours corresponds in each case to the ranking position. The higher the rank (the darker the colour) the higher level of turbulence in a given period. A given market is included in the ranking only if empirical observations for least 50% of days in the given period were available. Slovakia, Estonia, Latvia, Lithuania, and Croatia dropped out of the ranking due to joining the Eurozone in respective years; Bulgaria and Switzerland dropped out due to the phasing out of the IBOR rates in respective years.

Source: Authors' calculations.

Above all, however, the comparative level of turbulence across different markets appeared variable. For instance, Ukraine, Russia, Romania, and Croatia occupied lower positions in all the rankings, reflecting a comparatively high level of turbulence that remained relatively stable over time (as adjusted for systemic risk turbulence in the larger financial system). On the other hand, Denmark showed a similarly stable but low position in the rankings, indicating a low level of turbulence in comparison to other countries.

A different situation was observed in the Eurozone, Switzerland, Sweden, and the UK, which despite their generally low ranks in most subperiods, spiked in the rankings for single periods, changing ranks from less turbulent to more turbulent positions. The fact that these ranks changed for single subperiods shows that the increase in turbulence relative to other markets was larger in the spiking market, and it affected that market particularly strongly relative to others. This suggests that if spillovers of this turbulence to other markets took place, they were not very pronounced.

Global occurrences, such as the COVID-19 pandemic, did not significantly shake-up the rankings. This suggests that the largest systemic shocks affected all the interbank markets equally. On the other hand, the most recent systemic event, i.e. the war in Ukraine, placed the countries that are in a closer (economic or geographic) proximity to this crisis in higher ranks, further demonstrating the uniqueness of risk in each interbank market. From a theoretical standpoint this suggests that the IBOR rates in the CEE region reacted properly to this turbulence, incorporating the actual information about the increased risk for the banking sector indicated previously in the literature review.

5.4 Co-occurrence of turbulence in interbank markets and systemic risk spillovers

Finally, the interbank market turbulence measure (ITM) was contrasted with the conditional Value at Risk ($\Delta CoVaR$) model applied to measure systemic risk of the analysed banking systems to investigate whether the spikes in the two risk measures co-occurred in time. All the CoVaR and ITM series were normalised, i.e. transformed linearly to fill the range from 0 to 1. Next, moving averages of the order of 60 for all the normalised series were calculated (this corresponds to a period of about 3 months[8]). Then the course of the CoVaR and its moving average were superimposed on the ITM and its moving average. For the sake of clarity, each latter pair of turbulence indicators was scaled by modifying its amplitude. This makes the relative differences in sizes of the risk spikes uninterpretable, but allows for a more precise analysis of the timing. For illustration, the four described time series for each system were plotted in Figures 5 to 8 presented below, and A1 to A14[9] in Appendix.

Both measures point to systemic risk materialization during six turbulent periods: the global financial crisis (2008-2009), LIBOR scandals (2010), the public debt crisis (2011-2012 and 2015), Brexit (2016), the COVID-19 pandemic (2020), and war in Ukraine (2022-2023). This indicates the effectiveness of both measures in measuring the two different but corresponding dimensions of systemic risk: interbank market turbulence and contagion.

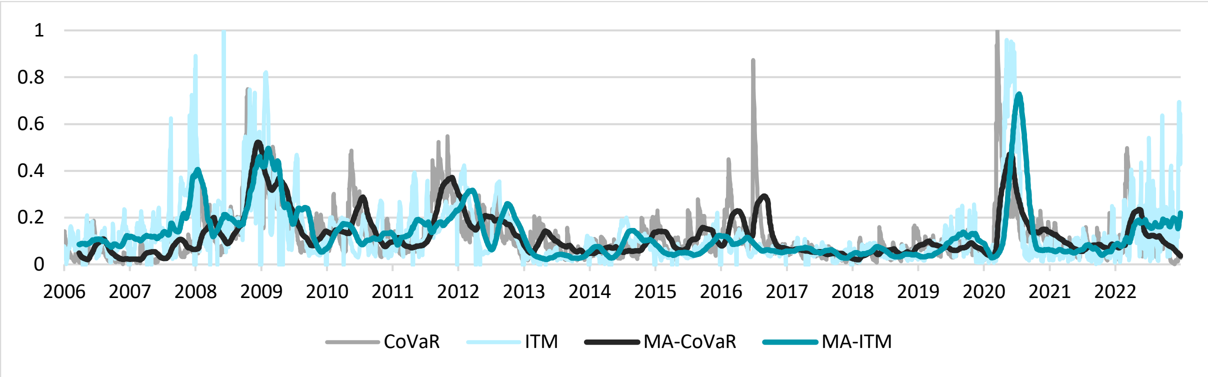


Fig. 5. Comparison of ITM and CoVaR for Eurozone

Source: Authors' calculations.

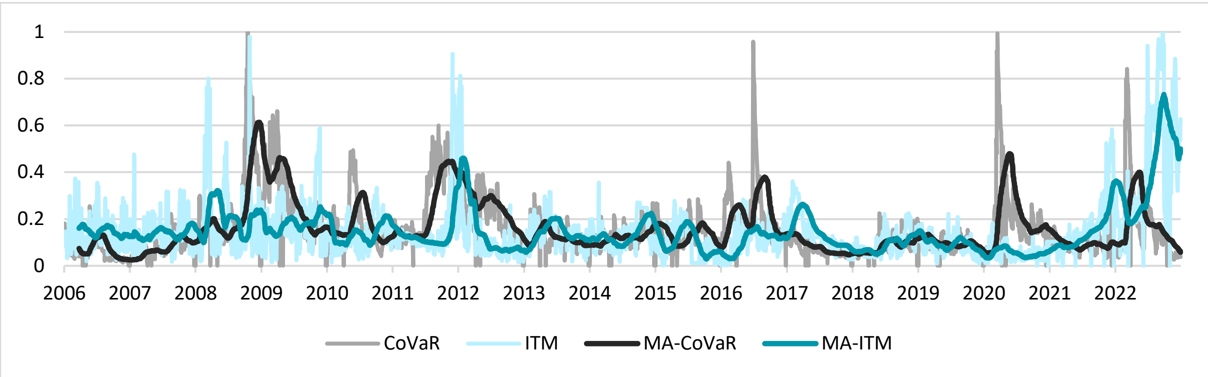


Fig. 6. Comparison of ITM and CoVaR for Hungary

Source: Authors' calculations.

[8] The results are robust also for other, shorter, and longer windows of the moving averages.

[9] Due to data limitations it was impossible to estimate ΔCoVaR for Ukraine, but the results of the ITM estimation discussed earlier are provided in Figure A15.

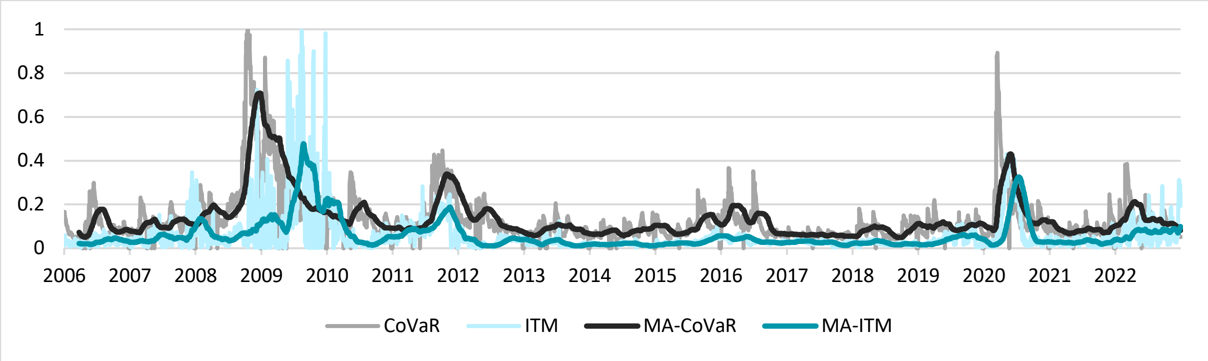


Fig. 7. Comparison of ITM and CoVaR for Lithuania

Source: Authors' calculations.

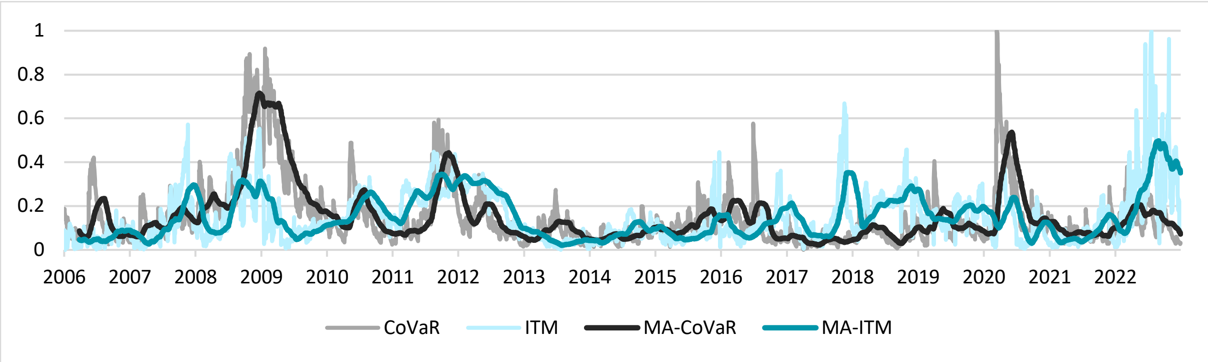


Fig. 8. Comparison of ITM and CoVaR for Sweden

Source: Authors' calculations.

Estimated models captured systemic risk spikes in various banking systems that did not spill over to the interbank markets (e.g. effects of Brexit in countries other than the UK) and those that occurred shortly before risk peaks in the interbank rates, in particular in highly turbulent periods (not only global financial crisis, but also the war). Interestingly, after 2007 – marked by two risk peaks in the interbank markets that preceded the CoVaR peaks and aligned with the onset of the global financial crisis – the typical order of risk materialization did not appear. Moreover, after 2008, none of the analyzed CEE countries show cases where risk first intensified in the interbank market and subsequently in the banking system. Furthermore, after 2008, there were no situations in which the increase in risk appeared first in the interbank market, and subsequently in the banking system for any of the analysed CEE countries. However, the results suggest that risk could be spilling over from the banking systems into the interbank markets, which points to the need for further research.

The study provided another systematic observation concerning the turbulence measured by the ITM in contrast to the CoVaR. For the CEE countries, the level of turbulence in IBOR rates decreased significantly after 2014, which indicates a general decrease in their susceptibility to systemic risk. This decrease was not accompanied by a similar reduction in banking sector systemic risk measured by the CoVaR model, so it was a specific characteristic of the studied IBORs. This coincided with various regulatory actions that were intended to improve the robustness of IBOR rates, confirming the expectations formulated in Hypothesis 1.

Nevertheless, the obtained results also indicate that there were no spillovers of systemic risk from CEE interbank markets to their banking sectors. Therefore, Hypothesis 2 was rejected. In addition, the observation that interbank markets were susceptible to systemic risk materialising in the banking system, indicates the need for particular caution when adopting new reference rates and the related reform of interbank systems.

These findings are unique and difficult to compare to any other existing studies. They are, however, parallel to the study of Molnar and Csiszárik-Kocsír (2024), who found that the total and directional spillovers between EURIBOR and Budapest Interbank Offered Rate (BUBOR) were extremely low – only about 6.3% of the volatility forecast error variance came from these spillovers. They also documented that BUBOR was primarily a net receiver of spillovers from the Hungarian MAX short-term government bond benchmark rather than the EURIBOR.

The findings presented here also align with the results of Eross et al. (2016) who examined the illiquidity contagion in the interbank market by modelling the interaction among the LIBOR-OIS spread, the euro fixed-float OIS swap rate, and the three-month US-German bond spread. They found a unidirectional relationship from the larger market to the interbank market (and not vice versa). They also showed how structural breaks identified as prospective financial crises generated liquidity shocks driving the interbank rates and spread fluctuations. Finally, they discovered strong evidence that when the short-term interbank market is affected by a liquidity shock, the LIBOR-OIS spread is a leader in moving back to equilibrium, while the euro-dollar currency swap rate and the US-German bond spreads are followers. These findings indicate phenomena similar to those described in this paper.

6 Discussion: challenges of the transition and their implications for the advanced and emerging markets

There are many significant challenges and risks related to transitioning from IBOR-based markets to markets based on alternative reference rates. These challenges are greater for the less developed financial markets and particularly difficult for many emerging European countries. The risk implications of transition that affect both developed and emerging markets are summarised in Table 2.

Table 3. Selected risk implications of the transition for the banking system

Risk type	Examples of what might be affected
Credit risk	Floating rate loans, counterparty creditworthiness, banks' capital requirements, banks' contractual exposures
Interest rate risk	Monetary policy transmission mechanisms, forward rates, term structure implications
Investment risks	Derivatives, long-term investments, hedging and portfolio strategies
Legal risk	Legacy financial contracts, cost of rolled-over debt, unintended consequences of the contractual fallback provisions
Liquidity risks	Pricing, access to capital, access to instruments, rate of market development
Model risk	Existing pricing and risk models, risk measurement and management, hedging
Operational risk	System changes for computation of interest, prices, term structures, etc.
Regulatory risk	Adequacy and effectiveness of current and future regulation, creating a new unregulated margin on loans and deposits, costs of legal advice, and potential lawsuits
Systemic risk	Systemic liquidity, fragility, risk spillovers, market transparency, completeness, integration, fragmentation

Caption: The table presents selected risk implications for the transition from the IBOR rate towards their replacements, with particular focus on the challenges that apply directly to emerging markets.

Source: Authors' elaboration.

Several challenges are more easily faced in more liquid and developed markets, and one such challenge relates to finding good alternatives. Schrimpf and Sushko (2019) argue that the ideal reference rate must provide an accurate, robust representation of core money market rates at a given moment, but it should also offer a good reference for financial contracts and term-based financing. Despite it being the agenda of all European regulators for the last five years, some countries, e.g. Romania, have not decided yet on the new reference rate benchmark.

The regulators argue that by design, the new alternative rate should bear the characteristics of a true risk-free rate. However, as Bryan and Rafferty (2016) pointed out, LIBOR “was believed to provide a risk-free rate of interest”, yet it “has been revealed to be risk-laden”, and now it is becoming surpassed by financial market practices, because the market is increasingly concerned with measures of interest rate volatility and not the price itself. In fact, Kirti (2022) showed that reference rates that capture true levels of credit risk instead of simply being risk-free could improve the welfare of the banking sector and society.

Schrimpf and Sushko (2019) also claim that – while the new risk-free rates (RFRs) can serve as robust and credible overnight reference rates rooted in transactions in liquid markets – they do so at the expense of not capturing banks’ marginal term funding costs. Hence, there is a possibility that, under a new normal, multiple rates could coexist, fulfilling different purposes and market needs. These arguments put in question whether the rate replacement approaches taken by the regulators are correct.

Kubacki (2023) emphasises that different European countries look for their own individual ways to establish the new benchmarks, but this leads to a significant divergence in a once consistent and convergent financial market in the EU. Cooperman et al. (2022) found that using a truly risk-free rate as a reference rate may exacerbate bank funding frictions that used to be mitigated in the IBOR-based markets. They report a potential solution to that problem that is not directly applicable to the banks in smaller markets due to liquidity concerns. Monetary policy concerns in the CEE region are also substantial.

Kapuściński (2023) provided first estimates regarding the efficiency of monetary policy transmission in Poland using the new overnight rates (Warsaw Interest Rate Overnight, WIRON), and found a transmission mechanism similar to that of the POLONIA rate, yet distinct from the one observed for WIBOR rates. The observed differences in transmission lags could negatively impact the monetary policy transmission mechanism in Poland; however, it is impossible to state this with certainty, as the number of applicable observations is still very limited. Kozińska (2023) indicates that the new replacement rate may potentially be acceptable for the international markets, but it requires a high number of transactions and imposes the necessity of a larger educational reform in Poland with respect to rate fixing.

Other studies also put in question whether the rate replacement approaches taken by the regulators are correct. Klingler and Syrstad (2021) demonstrated that the alternative reference rates set to replace the LIBOR are not actually risk-free and they strongly depend on marginal lenders, regulatory constraints, the amount of government debt outstanding (more so for collateralised rates) and central bank reserves. They also show that term rates based on alternative reference rates can be detached from banks’ marginal funding costs, which poses a problem for bank loans (p. 798).

Similarly, Baig and Winters (2022) question the underlying process behind the choice of Secured Overnight Financing Rate (SOFR) as a replacement for LIBOR, arguing that both academic literature and regulatory bodies fail to identify a consistent definition and criteria of a good reference rate, and provide an empirically testable checklist to evaluate the suitability of alternative reference rates. Their empirical evaluation of various money market rates identified the one-month AA non-financial commercial paper rate as the best available replacement for LIBOR.

Comparability was one of the key features of the IBOR rates that allowed emerging financial markets to develop faster, by making them more open and similar to the more liquid developed markets. All the new rates were designed to be very similar to each other; however, observations from recent years reveal that this assumption diverges significantly from actual outcomes. As a result of a lack of uniform rules, starting from 2025 when the full transition is supposed to occur, incomparable rates will operate in different financial markets. They will reflect the specificity of the local market, as intended, but it will not necessarily be possible to make cross-country comparisons using them as a basis. Moreover, since some IBOR rates are unsecured, they will contain credit risk, while the new alternative reference rates will be assumed to be risk-free.

Despite the crucial role of the IBOR rates in setting the term structures, most of the replacement rates selected by the developed markets are rates with one simple (usually overnight or one-day) maturity. Huang and Todorov (2022) suggested that for this reason, the markets should find other points of reference for derivatives, and pricing, among others, and define the role of the reference rate anew. This is easier in markets where overnight index swaps create a liquid market compared to the emerging and frontier markets where they do not.

The alternative would be to derive the term structure based on a flat retrospective reference rate such as the euro short-term rate (€STR). Various authors proposed different solutions to this challenge (Duffie, 2018; Henrard, 2019; Lyashenko, & Mercurio, 2019; ECB, 2021). This multiplicity also relates to the fact that different fallback rates are available in different countries, and for many emerging ones, there are very limited choices. Thus, there is no clear way forward, and arriving at a new cross-border standard for setting term structure is difficult to foresee.

The need for a term structure is not only a matter of valuation but also of the entire transfer pricing mechanism (and the valuation of individual balance sheet elements). Developed markets have quotations based on the overnight indexed swap (OIS) term structure (see Table A2 in Appendix), which could naturally substitute for the replaced IBOR, thanks to their minimised credit risk and long history of quotations. However, smaller markets that do not have OIS (e.g. Romania) or where the swap markets are not particularly deep (e.g. Poland) are forced to adopt the same solutions, despite higher risks. Therefore, abolishing IBOR leaves a gap related to the lack of a commonly established, uniform, and equally risk-bearing term structure.

One of the biggest drawbacks of the alternative rates recently applied by the United States and the European Union is their retrospective nature. Constructing a term structure based on this rate requires completely different mechanisms than those used to establish an IBOR-based one. The IBOR rates included a promise (readiness) to conclude transactions at a given future rate, while the new benchmark rates refer only to the past. Thus, any curves that may be constructed based on such rates are historical and have less predictive power. They also do not take into account the liquidity premium or the well-founded term structure hypotheses (e.g. liquidity preference theory or market segmentation theory). Therefore, it is necessary to create a mechanism for building a forward-looking curve and converting the retrospective structure into a forward-looking one. Thus, there is a new basis and model risk source, where the interest on contracts anchored to the new rate will not be effectively known in advance, making hedging much more difficult than before.

It is unclear how the transition will affect the liquidity of the emerging interbank markets. The systemic risk implications are even more vague. In general, the robustness of the markets should rise if the selected benchmarks are closer to the risk-free rates, but the cross-border differences may impede development, lower liquidity, and bring about significant systemic risk implications for the banking sector. European market integration has already been affected by the desynchronised transition, and with each alternative solution adopted by a new country, the potential of market fragmentation increases. The lack of a unified cross-border standard can be a source of model risk and space for capital and regulatory arbitrage.

It is a fact that no interest rate in the history of the financial markets was free from systemic turbulence, and setting a new benchmark without a firm analysis of systemic risk implications opens any banking system to new fragilities and systemic exposures. Unfortunately, given various limitations, for many emerging markets, truly robust analyses of this kind are impossible at this time. Systemic risk is too complex, and there are too many unknowns involved.

Empirical results indicate that systemic risk related to IBOR rates dropped significantly in the last ten years in the CEE region. The rates are still reacting to significant systemic risk triggers such as the war in Ukraine, but it does not seem to be the source of systemic risk itself. The sequence of reactions to systemic risk in the emerging markets suggests a direction of risk spillovers originating in the banking system, and not in the interbank markets themselves.

This study supports several other papers that provided arguments against the abandonment of the LIBOR rates, and in favour of their reform. McAndrews et al. (2017) empirically confirmed that the Federal Reserve's Term Auction Facility helped to ease strains in the interbank market, mitigating the liquidity problems in the interbank funding market. Gandhi et al. (2019) validated this point, showing that public enforcement, with the threat of large penalties and the loss of reputation, can be effective in deterring financial market misconduct and rate manipulation. Building on this, Huan et al. (2023) argue that the benchmark reform concurs with the paradigm shift toward the public interest approach to banking regulation.

In a similar spirit, Eisl et al. (2017) formulated alternative fixing methods for LIBOR and EURIBOR that could significantly reduce the effects of manipulation without liquidating these reference rates. Coulter et al. (2018) also proposed a new method for constructing LIBOR that produces an unbiased estimator of the true rate and works even in markets in which there are few transactions. Therefore, it could be particularly valuable to the CEE region. Finally, Li et al. (2021) demonstrated that regulators of poll-based interest rate benchmarks in emerging markets should pay attention to the intertemporal limitations of submissions, and developed the index that can be utilised in the quality control of panel bank submissions.

To sum up, the challenges of transition that may increase systemic risk in the emerging markets in Europe raise concerns that the new solutions may not be optimal from the perspective of systemic risk. The literature and the findings of this study support these concerns: the analysis reveals no evidence of significant systemic turbulence spillovers across IBOR markets in the CEE region, which provides no justification for abandoning these benchmarks. This contrasts sharply with the current policy direction, which moves forward with benchmark reforms despite the lack of systemic risk-based rationale. This situation is particularly troubling in light of the potential amplifiers of systemic risk and the possible decline in interbank market liquidity in the CEE region linked to the reference rate reforms, all of which suggest that the new frameworks may be suboptimal in terms of systemic stability.

7 Conclusions

This paper addressed the gap of the comprehensive analysis of emerging market IBOR rates in the context of systemic risk materialising in Europe, particularly in terms of turbulence spillovers between the IBOR rates and the banking system. Several innovations were applied to enable systemic turbulence measurement and to obtain results that would be otherwise not attainable for most of the emerging markets analyzed in this paper. Based on a case-by-case basis and a comparative analysis across developed, emerging and frontier markets, a broad view of different systemic characteristics in Europe was established.

The empirical results suggest that the turbulence in the IBOR rates subsided significantly in the CEE markets after the banking sector and IBOR rate reforms. In comparison, the LIBOR and EURIBOR rates were characterised by a lesser decrease in risk. No clear evidence of spillovers between the different IBOR rates was found, except for the LIBORs denominated in GBP and CHF, and to a lesser extent – the EURIBOR. No immediate direct spillovers between the IBOR rates and the systemic risk of the banking system were observed, only turbulence in the IBOR rates that followed ΔCoVaR spikes, and this characteristic was consistent in both advanced and emerging markets.

Given these results, the challenges of transition and the uncertainty about the actual risk characteristics of the alternative rates, it is questionable whether the transition truly offers better alternatives for emerging markets at this point in time. The risk implications for the challenges ahead and the discrepancy between the assumed shape of the reform and the reality of its application to emerging markets in Europe justify the concern that the new solutions may not be optimal from the systemic risk perspective.

These conclusions call for further research. Above all, the investigation of the actual materialised turbulence and systemic risk spillovers from the new rates adopted in Europe is necessary, once the data becomes available. At the same time, a continued surveillance of the impacts on monetary policy transmission mechanism and liquidity impacts on the interbank markets is required. Other avenues of research relate to the impacts of the new rates in the CEE region on financial markets' integrity, fragmentation and efficiency. The particular shape and methodology of such studies will depend on the actual final outcome of the transformation which is still unknown.

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References

Aagaard, J. (2012). *Barclays trækker sig ud af CIBOR Barclays withdraws from CIBOR*. https://www.berlingske.dk/virksomheder/barclays-traekker-sig-ud-af-cibor

Abrantes-Metz, R. M., Kraten, M., D. Metz, D. A., & Seow, S. G. (2011a). Libor manipulation? *Journal of Banking & Finance*, *36*(1), 136-50. https://doi.org/10.1016/j.jbankfin.2011.06.014

Abrantes-Metz, R. M., Villas-Boas, S. B., & Judge, G. (2011b). Tracking the Libor rate. *Applied Economics Letters*, *18*(10), 893-899. https://doi.org/10.1080/13504851.2010.515197

Acemoglu, D., Ozdaglar A., & Tahbaz-Salehi, A. (2015). Systemic risk and stability in financial networks. *American Economic Review*, *105*(2). 564-608. https://doi.org/10.1257/aer.20130456

Acharya, V. V. (2009). A theory of systemic risk and design of prudential bank regulation. *Journal of Financial Stability*, *5*(3), 224-255.

Acharya, V. V., & Thakor, A. V. (2016). The dark side of liquidity creation: leverage and systemic risk. *Journal of Financial Intermediation*, 28 (October), 4-21. https://doi.org/10.1016/j.jfi.2016.08.004

Acharya, V. V., &. Steffen, S. (2020). *"Stress tests" for banks as liquidity insurers in a time of COVID*. VoxEU.org. Retrieved from: https://cepr.org/voxeu/columns/stress-tests-banks-liquidity-insurers-time-covid

Acharya, V. V., Gale, G., & Tanju, Y. (2011). Rollover risk and market freezes. *The Journal of Finance*, 66(4), 1177-1209. https://doi.org/10.1111/j.1540-6261.2011.01669.x

Acharya, V., & Bisin, A. (2014). Counterparty risk externality: centralized versus over-the-counter markets. *Journal of Economic Theory*, 149 (January), 153-82. https://doi.org/10.1016/j.jet.2013.07.001

Acharya, V., & Rajan, R. (2024). Liquidity, liquidity everywhere, not a drop to use: Why flooding banks with central bank reserves may not expand liquidity. *The Journal of Finance*, *79*(5), 2943-2991. https://doi.org/10.1111/jofi.13370

Adrian, T., & Brunnermeier, M. K. (2016). CoVaR. *American Economic Review*, *106*(7), 1705-1741. https://doi.org/10.1257/aer.20120555

Afonso, G., & Shin, S. H. (2011). Precautionary demand and liquidity in payment systems. *Journal of Money, Credit and Banking*, *43*(October), 589-619. https://doi.org/10.1111/j.1538-4616.2011.00454.x

Afonso, G., Kovner, A., & Schoar, A. (2011). Stressed, not frozen: The federal funds market in the financial crisis. *Staff Report*, 437. Federal Reserve Bank.

Allen, F., . Babus, A., & Carletti, E. (2012). Asset commonality, debt maturity and systemic risk. *Journal of Financial Economics*, *104*(3), 519-34. https://doi.org/10.1016/j.jfineco.2011.07.003

Allen, F., & Babus, A. (2009). Networks in finance. In P. R. Kleindorfer, & Y. Wind (Eds)*The network challenge. strategy, profit, and risk in an interlinked world* (pp. 367–382). Wharton School Publishing.

Allen, F., & Gale, D. (2000a). Bubbles and crises. *The Economic Journal*, *110*, 236-55.

Allen, F., & Gale, D. (2000b). Financial contagion. *Journal of Political Economy, 108*, 1-33.

Allen, F., Carletti, E., & Gale, D. (2009). Interbank market liquidity and central bank intervention. *Journal of Monetary Economics*, *56*, 639-52.

Anand, K., Gai, P., Kapadia, S., Brennan, S., & Willison, M. (2013). A network model of financial system resilience. *Journal of Economic Behavior & Organization*, *85*, 219–235. https://doi.org/10.1016/j.jebo.2012.04.006

Aragon, G., & Strahan, Ph. (2009). Hedge funds as liquidity providers: evidence from the Lehman bankruptcy. Working Paper, 15336. National Bureau of Economic Research.

Ashton, P., & Christophers, B. (2015). On arbitration, arbitrage and arbitrariness in financial markets and their governance: Unpacking LIBOR and the LIBOR scandal. *Economy and Society*, *44*(2), 188-217. https://doi.org/10.1080/03085147.2015.1013352

Atanasov, V., Davies, J. R., & Merrick, J. J. (2015). Financial intermediaries in the midst of market manipulation: did they protect the fool or help the knave? *Journal of Corporate Finance*, *34*(October), 210-34. https://doi.org/10.1016/j.jcorpfin.2015.07.011

Babus, A. (2016). The formation of financial networks. *The RAND Journal of Economics, 47*(2), 239-72. https://doi.org/10.1111/1756-2171.12126

Babus, A., & Hu, T.-W. (2017). Endogenous intermediation in over-the-counter markets. *Journal of Financial Economics*, *125*(1), 200-215. https://doi.org/10.1016/j.jfineco.2017.04.009

Bahoo, S. (2020). Corruption in banks: A bibliometric review and agenda. *Finance Research Letters*, *35*, 101499. https://doi.org/10.1016/j.frl.2020.101499

Baig, A., & Winters, D. B. (2022). The search for a new reference rate. *Review of Quantitative Finance and Accounting*, *58*(3), 939-976. https://doi.org/10.1007/s11156-021-01014-y

Bailey, A. (2019). "LIBOR: preparing for the end." Speech by Andrew Bailey, Chief Executive of the FCA, at the Securities Industry and Financial Markets Association's (SIFMA) LIBOR Transition Briefing in New York, USA. July 15. https://www.fca.org.uk/news/speeches/libor-preparing-end.

Bank of England, BoE. (2021). *2021 list of UK firms designated as other systemically important institutions (O-SIIs) and scores*. https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/crd-iv/2021-list-of-uk-firms-designated-as-osiis.pdf

Bank of England, BoE. (2022). *2022 list of UK firms designated as other systemically important institutions (O-SIIs).* https://www.bankofengland.co.uk/prudential-regulation/publication/2022/november/2022-list-of-uk-firms-designated-as-osiisBank

Bank of England, BoE. (2023). *Transition to sterling risk free rates from LIBOR*. https://www.bankofengland.co.uk/markets/transition-to-sterling-risk-free-rates-from-libor 2023

Bank of Russia, BoR. (2022). *List of systemically important credit institutions approved*. https://www.cbr.ru/eng/press/pr/?id=38141

Bariviera, A. F., Guercio, M. B., Martinez, L. B., & Rosso, O. A. (2016). Libor at crossroads: Stochastic switching detection using information theory quantifiers. *Chaos, Solitons & Fractals*, *88*, 172-182. https://doi.org/10.1016/j.chaos.2016.02.009

Benoit, S., Colliard, J.-E., Hurlin, C., & Pérignon, C. (2017). Where the risks lie: a survey on systemic risk. *Review of Finance*, *21*(1), 109-52. https://doi.org/10.1093/rof/rfw026

Bessembinder, H., Hao, J., & Lemmon, M. L. (2011). *Why Designate Market Makers? Affirmative Obligations and Market Quality*. SSRN Scholarly Paper No. 989061.

Blåvarg, M., & Nimander, P. (2002). Interbank exposures and systemic risk. *Sveriges Riksbank's Economic Review*, *2*, 19-45.

Boss, M., Elsinger, H., Summer, M., & Thurner, S. (2004). Network topology of the interbank market. *Quantitative Finance*, *4*, 677-84.

Boyson, N. M., Stahel, W. C., & Stulz, M. R. (2010). Hedge fund contagion and liquidity shocks. *Journal of Finance*, *65*, 1789--816.

Braml, H.(2016). The manipulation of LIBOR and related interest rates. *Studies in Economics and Finance*, *33*(1), 106-25. https://doi.org/10.1108/SEF-10-2014-0203

Brownlees, C., & Engle, R. F. (2017). SRISK: A Conditional Capital Shortfall Measure of Systemic Risk. *Review of Financial Studies*, *30*(1), 48-79. https://doi.org/10.1093/rfs/hhw060

Brunnermeier, M. K. (2008). Bubbles. In Palgrave Macmillan (Ed.), *The New Palgrave Dictionary of Economics* (pp. 1–8). Palgrave Macmillan UK. https://doi.org/10.1057/978-1-349-95121-5_44-2

Brunnermeier, M. K., & Pedersen, H. L. (2009). Market liquidity and funding liquidity. *Review of Financial Studies*, *22*, 2201-38.

Brunnermeier, M. K., & Oehmke, M. (2013). The maturity rat race. *The Journal of Finance*, *68*, 483-521.

Brunnermeier, M. K., & Sannikov, Y. (2014). A macroeconomic model with a financial sector. *The American Economic Review*, *104*, 379-421.

Brunnermeier, M. K., Eisenbach, M. T., & Sannikov, Y. (2013). Macroeconomics with financial frictions: A survey. In *Advances in Economics and Econometrics, Tenth World Congress of the Econometric Society*. Cambridge University Press, vol. 2, pp. 3-96.

Bryan, D., & Rafferty, M. (2016). The unaccountable risks of LIBOR. *The British Journal of Sociology*, *67*(1), 71-96. https://doi.org/10.1111/1468-4446.12177

Buiter, W. H. (2008). Central banks and financial crises. *Discussion paper*, 619. Financial Markets Group, London School of Economics and Political Science.

Burgess, N. (2020). How Risky is your Project Really? Corporate finance strategies for assessing risk. Retrieved from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3748822

Caballero, R., & Simsek, A. (2013). Fire Sales in a Model of Complexity. *The Journal of Finance*, *68*, 2549-87.

Castiglionesi, F., & Navarro, N. (2011). Fragile financial networks. Working paper. Tilburg University. Retrieved from: https://research.tilburguniversity.edu/en/publications/optimal-fragile-financial-networks

Cespa, G., & Foucault, T. (2014). Illiquidity contagion and liquidity crashes. *Review of Financial Studies*, *27*, 1615-60.

CFA Institute, CFA. (2022). *Systemic risk and management in finance*. Retrieved August 23, 2022, from https://www.cfainstitute.org/en/advocacy/issues/systemic-risk

Chan-Lau, J. A., Espinosa, M., & Sole, J. (2009). On the use of network analysis to assess systemic financial linkages. *Global Financial Stability Report*. International Monetary Fund.

Chen, D., & Duffie, D. (2021). Market fragmentation. *American Economic Review*, *111*(7), 2247-74. https://doi.org/10.1257/aer.20200829

Cifuentes, R., Hyun S., & Ferrucci, G. (2005). Liquidity risk and contagion. *Journal of the European Economic Association*, *3*, 556-66.

Clementi, D. (2001). *Financial markets: Implications for financial stability*. *Balance Sheet*, *9*(3), 7-12.

Cooperman, H., Duffie, D., Luck, S., Wang, Z., & Yang, Y. (2022). Bank funding risk, reference rates, and credit supply. Federal Reserve Bank of New York Staff Reports, No. 1042.

Coulter, B., Shapiro, J., & Zimmerman, P. (2018). A mechanism for LIBOR. *Review of Finance*, *22*(2), 491-520. https://doi.org/10.1093/rof/rfx045

Coval, J., & Stafford, E. (2007). Asset fire sales (and purchases) in equity markets. *Journal of Financial Economics*, *86*(2), 479-512.

Covi, G., & Gu, X. (2022). Interbank network and banks' credit supply. Bank of England Staff Working Paper No. 1,005. November. https://www.bankofengland.co.uk/-/media/boe/files/working-paper/2022/interbank-network-and-banks-credit-supply.pdf

Cox, J. C., Ingersoll, J., & Ross, S. (1981). The relation between forward prices and futures prices. *Journal of Financial Economics*, *9*, 321-46.

Danielsson, J., Macrae, R., & Micheler, E. (2017). Brexit and systemic risk. LSE Research Online Documents on Economics, 85124, London School of Economics and Political Science, LSE Library.

Dao, T. M., McGroarty, F. &Urquhart, A. (2019). The Brexit vote and currency markets. *Journal of International Financial Markets, Institutions and Money*, *59*(March), 153-64. https://doi.org/10.1016/j.intfin.2018.11.004

de La Grandville, O. (2003). *Bond Pricing and Portfolio Analysis: Protecting Investors in the Long Run*. MIT Press.

Diamond, D. W., & Rajan, G. R. (2005). Liquidity shortages and banking crises. *Journal of Finance*,*60*, 615-47.

Duffie, D. (2014). Financial market infrastructure: too important to fail. In M. N. Baily & J. B. Taylor (Eds.). *Across the Great Divide: New Perspectives on the Financial Crisis*. Book Chapter 11. 251-57. Hoover Institution, Stanford University.

Duffie, D. (2018). Compression auctions with an application to LIBOR-SOFR swap conversion. *Technical Report*. Graduate School of Business, Stanford University.

Duffie D. (2020). Still the world's safe haven? Redesigning the U.S. treasury market after the COVID-19 crisis. *Hutchins Center Working Papers*, *62*, June.

Duffie, D. (2022). Why government bond markets get dysfunctional—and what to do about it. Conference speech. Annual Financial Market Liquidity Conference Budapest, Hungary, 10-11 November 2022.

Duffie, D., & Zhu, H. (2011). Does a central clearing counterparty reduce counterparty risk? *Review of Asset Pricing Studies*, *1*(1), 74-95. https://doi.org/10.1093/rapstu/rar001

Duffie, D., & Stein, C. J. (2015). Reforming LIBOR and other financial market benchmarks. *Journal of Economic Perspectives*, *29*(2), 191-212. https://doi.org/10.1257/jep.29.2.191

Dziwok, E., & Karaś, A. M. (2021). Systemic illiquidity noise-based measure—a solution for systemic liquidity monitoring in frontier and emerging markets. *Risks*, *9*(7), 124. https://doi.org/10.3390/risks9070124

EBA. (2020). The EU banking sector: First insights into the COVID-19 impacts thematic note, EBA/REP/2020/17.

EBA. (2022). Global systemically important institutions (G-SIIs). https://www.eba.europa.eu/risk-analysis-and-data/global-systemically-important-institutions

Eisenberg, L., & Noe, H. T. (2001). Systemic risk in financial systems. *Management Science*, *47*(2), 236-49. https://doi.org/10.1287/mnsc.47.2.236.9835

Eisl, A., Jankowitsch, R., & Subrahmanyam, M. G. (2017). The manipulation potential of Libor and Euribor. *European Financial Management*, *23*(4), 604-647. https://doi.org/10.1111/eufm.12126

Elliott, M., Golub, B., & Jackson, O. M. (2014). Financial networks and contagion. *American Economic Review*, *104*(10), 3115-53. https://doi.org/10.1257/aer.104.10.3115

Elsinger, H., Lehar, A., & Summer, M. (2006). Risk assessment for banking systems. *Management Science*, *52*(9), 1301-14. http://www.jstor.org/stable/20110606

Engle, R. F., & Zazzara, C. (2018). Systemic risk in the financial system: Capital shortfalls under Brexit, the US elections and the Italian referendum. *Journal of Credit Risk*, *14*(4) .

Eross, A., Urquhart, A., & Wolfe, S. (2016). Liquidity risk contagion in the interbank market. *Journal of International Financial Markets, Institutions and Money*, *45*, 142155. https://doi.org/10.1016/j.intfin.2016.07.005

European Systemic Risk Board, ESRB. 2022. "Systemically Important Institutions." https://www.esrb.europa.eu/national_policy/systemically/html/index.en.html

European Central Bank, ECB. (2020). Financial Stability Review. https://www.ecb.europa.eu/pub/pdf/fsr/ecb.fsr202011~b7be9ae1f1.en.pdf

European Central Bank, ECB. (2021). Recommendations by the working group on euro risk-free rates on EURIBOR fallback trigger events and €STR-based EURIBOR fallback rates. Frankfurt am Main, May 11.

Fabrizi, M., Huan, X., & Parbonetti, A. (2021). When LIBOR becomes LIEBOR: Reputational penalties and bank contagion. *Financial Review*, *56*(1), 157178. https://doi.org/10.1111/fire.12240

Farboodi, M. (2023). Intermediation and Voluntary Exposure to Counterparty Risk. *Journal of Political Economy*, *131*(12), 3267–3309. https://doi.org/10.1086/725168

Financial Conduct Authority, FCA. (2021). Announcements on the end of LIBOR. March 5. Press release. https://www.fca.org.uk/news/press-releases/announcements-end-libor

Financial Market Supervisory Authority, FINMA. (2022). Systemically important banks. https://www.finma.ch/en/enforcement/recovery-und-resolution-n/publikationen/publikation-wesentlicher-gruppengesellschaften/

Flannery, M. J. (1996). Financial crises, payment system problems, and discount window lending. *Journal of Money, Credit and Banking*, *28*, 804-24.

Freifeld, K. (2015). Five global banks to pay $5.7 billion in fines over rate rigging. Reuters Report, https://www.reuters.com/article/us-banks-forex-settlementa-usa-idUSKBN0O51PY20150520

Freixas, X., Parigi, M. B., & Rochet, C. J. (2000). Systemic risk, interbank relations, and liquidity provision by the central bank. *Journal of Money, Credit and Banking*, *32*(3), 611-638.

Gabrieli, S., & Co-Pierre G. (2014). A network view on interbank market freezes. *Discussion Paper*, 44/2014. Deutsche Bundesbank.

Gai, P., & Kapadia, S. (2010). Contagion in financial networks. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *466*(2120), 2401-23. https://doi.org/10.1098/rspa.2009.0410

Gandhi, P., Golez, B., Jackwerth, J. C., & Plazzi, A. (2019). Financial market misconduct and public enforcement: The case of Libor manipulation. *Management Science*, *65*(11), 5268-5289. https://doi.org/10.1287/mnsc.2018.3065

Geanakoplos, J. (2010). Solving the present crisis and managing the leverage cycle. *Economic Policy Review*, *16*(Aug), 101-31.

Gofman, M. (2015). *Efficiency and stability of a financial architecture with too-interconnected-to-fail institutions*. External Seminar Paper. International Monetary Fund.

Gordon, A. D. (1999). Classification, 2nd Edition. In Chapman & Hall (Eds.) *CRC Monographs on Statistics & Applied Probability*. CRC Press.

Gorton, G., & Ordonez, G. (2014). Collateral crises. *The American Economic Review*, *104*, 343-78.

Gromb, D., & Vayanos, D. (2002). Equilibrium and welfare in markets with financially constrained arbitrageurs. *Journal of Financial Economics*, *66*, 361-407.

Hattori, T.. (2021). Noise as a liquidity measure: evidence from the JGB market. *Pacific-Basin Finance Journal*, *67* (June), 101515. https://doi.org/10.1016/j.pacfin.2021.101515

Heider, F., Hoerova, M., & Holthausen, C. (2015). Liquidity hoarding and interbank market spreads: The role of counterparty risk. *Journal of Financial Economics*, *118*, 336-54.

Hennig, C. (2015). *FPC: Flexible Procedures for Clustering*. R package version 2, pp. 1–10.

Henrard, M. P. (2019). LIBOR fallback and quantitative finance. *Risks*, *7*(3), 88. https://doi.org/10.3390/risks7030088

Hernando-Veciana, Á., & Tröge, M. (2020). Cheap talk and strategic rounding in LIBOR submissions. *The Review of Financial Studies*, *33*(6), 2585-2621.

Hou, D. & Skeie, R. D. (2014). LIBOR: Origins, economics, crisis, scandal, and reform (March 1, 2014). FRB of New York Staff Report No. 667.

Hu, G. X., Pan, J., & Wang, J. (2013). Noise as information for illiquidity. *The Journal of Finance*, *68*, 2341-82. https://doi.org/10.1111/jofi.12083

Huan, X., Previts, G. J., & Parbonetti, A. (2023). Understanding the LIBOR scandal: The historical, the ethical, and the technological. *Journal of Banking Regulation*, *24*(4), 403-419. https://doi.org/10.1057/s41261-022-00205-4

Huang, W., & Todorov, K. (2022). The post-Libor world: A global view from the BIS derivatives statistics. *BIS Quarterly Review*, December.

ICE Benchmark Administration, IBA. (2014). *ICE LIBOR: Evolution of ICE LIBOR*. ICE Benchmark Administration. https://ir.theice.com/press/news-details/2016/ICE-Benchmark-Administration-Publishes-Roadmap-for-ICE-LIBOR/

Indriawan, I., Jiao, F., & Tse, Y. (2021). The SOFR and the Fed's influence over market interest rates. *Economics Letters*, *209*, 110095. https://doi.org/10.1016/j.econlet.2021.110095

International Monetary Fund, IMF. (2015). *Vulnerabilities, legacies, and policy challenges. Risks rotating to emerging markets*. Global Financial Stability Report, October.

International Organization of Securities Commission. (2018). Statement on matters to consider in the use of financial benchmarks. January, 5. https://www.iosco.org/library/pubdocs/pdf/IOSCOPD589.pdf

JP Morgan. (2019). Leaving Libor: a landmark transition. J.P. Morgan Global Markets. January https://www.jpmorgan.com/content/dam/jpm/cib/complex/content/markets/libor-sofr/pdf-0.pdf

James, J., & Weber, N. (2000). *Interest Rate Modeling*. John Wiley & Sons, Inc.

Kansal, S., & Melatur, S. G. (2020). IBOR transition – a more in-depth look (April 15). Retrieved from: https://ssrn.com/abstract=3585460

Kapuściński, M. (2023). Interest rate pass-through to risk-free rates in Poland. *NBP Working Papers Series*, *358*.

Karahan, C. C., & Soykök, E. (2023). On illiquidity of an emerging sovereign bond market. *Economic Systems*, 101073. https://doi.org/10.1016/j.ecosys.2023.101073

Keogh, E., & Ratanamahatana, C. A. (2005). Exact indexing of dynamic time warping. *Knowledge and Information Systems*, *7*, 358-386. https://doi.org/10.1007/s10115-004-0154-9

Kirti, D. (2022). What are reference rates for? *Journal of Banking & Finance*, *144*, 106635. https://doi.org/10.1016/j.jbankfin.2022.106635

Kiff, J. (2012). *Back to basics: What is LIBOR? Finance & Development*, 49(4), 33–35. International Monetary Fund. https://www.imf.org/external/pubs/ft/fandd/2012/12/basics.htm

Klingler, S., & Syrstad, O. (2021). Life after LIBOR. *Journal of Financial Economics*, *141*(2), 783-801. https://doi.org/10.1016/j.jfineco.2021.04.017

Koeppl, T., Monnet, C., & Temzelides, T. (2012). Optimal clearing arrangements for financial trades. *Journal of Financial Economics*, *103*(1), 189-203. https://doi.org/10.1016/j.jfineco.2011.08.008

Kozińska, M. (2023). Od WIBOR do WIRON – przesłanki reformy wskaźników referencyjnych stopy procentowej a stabilność polskiego systemu finansowego. *Bezpieczny Bank*, *91*(2), 61-90. https://doi.org/10.26354/bb.3.2.91.2023

Kubacki, D. (2023). Reformy referencyjnych stóp procentowych na wybranych rynkach finansowych. *Bezpieczny Bank*, *91*(2), 34-60. https://doi.org/10.26354/bb.2.2.91.2023

Kudenholdt, S. (2018). LIBOR — Hazards on the road to reform. *The Journal of Structured Finance*, *24*(1), 8-13. https://doi.org/10.3905/jsf.2018.24.1.008

Kuo, D., Skeie, R. D., & Vickery, I. J. (2018). A Comparison of Libor to other measures of bank borrowing costs. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3272370

Leitner, Y. (2005). Financial networks: Contagion, commitment, and private sector bailouts. *The Journal of Finance 60*(6), 2925-53. https://doi.org/10.1111/j.1540-6261.2005.00821.x

Li, M., Sun, H., & Zong, J. (2021). Intertemporal imitation behavior of interbank offered rate submissions. *Journal of Banking & Finance*, *132*, 106219. https://doi.org/10.1016/j.jbankfin.2021.106219

Lubiński, M. (2013). Międzynarodowy rynek pieniężny i zarażenie. *Gospodarka Narodowa. The Polish Journal of Economics*, *264*, 19-41.

Lucas, R. E. (1978). Asset prices in an exchange economy. *Econometrica*, *46*, 1429-45.

Lyashenko, A., & Mercurio, F. (2019). Looking forward to backward-looking rates: a modeling framework for term rates replacing LIBOR. *Technical Report*. http://dx.doi.org/10.2139/ssrn.3330240

Markose, S., Giansante, S., & Shaghaghi, R. A. (2012). 'Too interconnected to fail' financial network of US CDS market: Topological fragility and systemic risk. *Journal of Economic Behavior and Organization*, *83*(3), 627-46. https://doi.org/10.1016/j.jebo.2012.05.016

McAndrews, J., Sarkar, A., & Wang, Z. (2017). The effect of the term auction facility on the London interbank offered rate. *Journal of Banking & Finance*, *83*, 135-152. https://doi.org/10.1016/j.jbankfin.2016.12.011

McConnell, P. (2013). Systemic operational risk: The LIBOR manipulation scandal. *The Journal of Operational Risk*, *8*(3), 59-99. https://doi.org/10.21314/JOP.2013.127

Mehra, Y. P. (1995). Some key empirical determinants of short-term nominal interest rates. Federal Reserve Bank of Richmond. *Economic Quarterly*, *81*, 33-51.

Milligan, G. W., & Cooper, M. C. (1987). Methodology review: Clustering methods. *Applied Psychological Measurement,* 11, 329-354. https://doi.org/10.1177/014662168701100401

Molnar, A., & Csiszárik-Kocsír, Á. (2024). Do ECB's rate hikes have spillover effects on the Hungarian BUBOR and the EUR/HUF exchange rate? A five-variable VAR model approach using the Diebold-Yilmaz spillover table. *Journal of Corporate Accounting & Finance*, *35*(4), 39–57. https://doi.org/10.1002/jcaf.22716.

Montero, P., & Vilar, J. A. (2014). TSclust: an R Package for time series clustering. *Journal of Statistical Software*, *62*, 1-43. https://doi.org/10.18637/jss.v062.i01

Morris, S., & Shin, S. H. (2012). Contagious adverse selection. *American Economic Journal: Macroeconomics*, *4*(1), 1-21. https://doi.org/10.1257/mac.4.1.1

Nelson, Ch, R., & Siegel, F. A. (1987). Parsimonious modelling of yield curves. *Journal of Business*, 60, 473-89.

Nier, E.W., Yang, J., Yorulmazer, T., & Alentorn, A. (2008). Network models and financial stability. Bank of England Working Paper No. 346.

Office of Financial Research, OFR. (2015). Financial Stability Report, December. https://www.financialresearch.gov/financial-stability-reports/files/OFR_2015-Financial-Stability-Report_12-15-2015.pdf

Pala, M. (2024). COVID-19 and the fragmentation of the European interbank market. *Discussion Papers*, 07/2024, Deutsche Bundesbank. http://dx.doi.org/10.2139/ssrn.4268232

Petitjean, F., Ketterlin, A., & Gançarski, P. (2011). A global averaging method for dynamic time warping, with applications to clustering. *Pattern Recognition*, *44*, 678-693. https://doi.org/10.1016/j.patcog.2010.09.013

Pontines, V., & Rummel, O. (2023). LIBOR meets machine learning: A Lasso regression approach to detecting data irregularities. *Finance Research Letters*, *55*, 103852. https://doi.org/10.1016/j.frl.2023.103852

Qi, M., Shi, D., Feng, S., Wang, P., & Nnenna, B. A. (2022). Assessing the interconnectedness and systemic risk contagion in the Chinese banking network. *International Journal of Emerging Markets*, *17*(3), 889-913. https://doi.org/10.1108/IJOEM-08-2021-1331

Rauch, B., Goettsche, M. & El Mouaaouy, F. (2013). LIBOR Manipulation empirical analysis of financial market benchmarks using Benford's law. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2363895

Regulation (EU) 2016/1011 of the European Parliament and of the Council of 8 June 2016 on indices used as benchmarks in financial instruments and financial contracts or to measure the performance of investment funds and amending Directives 2008/48/EC and 2014/17/EU and Regulation (EU) No 596/2014. http://data.europa.eu/eli/reg/2016/1011/oj

Sakoe, H., & Chiba, S. (1971). A dynamic programming approach to continuous speech recognition. In: Presented at the Proceedings of the Seventh International Congress on Acoustics, Akad´emiai Kiad´o, Budapest, pp. 65–69.

Sakoe, H., & Chiba, S. (1978). Dynamic programming algorithm optimization for spoken word recognition. *IEEE Trans. Acoust. Speech Signal Process*, *26*, 43-49. https://doi.org/10.1109/TASSP.1978.1163055

Scheinkman, J. A., & Xiong, W. (2003). Overconfidence and speculative bubbles. *Journal of Political Economy*,*111*(6), 1183--1220. https://doi.org/10.1086/378531

Schmitz, H. (2011). Direct evidence of risk aversion as a source of advantageous selection in health insurance. *Economics Letters*, *113*, 180-82.

Schrimpf, A., & Sushko, V. (2019). Beyond LIBOR: A primer on the new benchmark rates. *BIS Quarterly Review*. Bank for International Settlements.

Schrimpf, A., Shin, S. H., & Sushko, V. (2020). Leverage and margin spirals in fixed income markets during the COVID-19 crisis. *BIS Bulletin*, *2*.Bank for International Settlements.

Schubert, E. (2017). *Knowledge discovery in databases*, Part III, Clustering.

Scott, H.. S. (2012). Interconnectedness and contagion. Committee on Capital Markets Regulation, 16-18, November 20.

Shiller, R., &. McCulloch, H. J. (1990). The term structure of interest rates. In B. M. Friedman and F. H. Hahn (Eds.) *Handbook of Monetary Economics* (pp. 627–722). Elsevier.

Shleifer, A., & Vishny, W. R. (1997). The limits of arbitrage. *The Journal of Finance*, *52*, 35-55.

Silva, W., Kimura, H., & Sobreiro, A. V. (2017). An analysis of the literature on systemic financial risk: a survey. *Journal of Financial Stability*, *28* (February), 91114. https://doi.org/10.1016/j.jfs.2016.12.004

Smaga, P. (2014). The concept of systemic risk. Systemic Risk Centre, LSE, *Special Paper Series*, *5*.

Stenfors, A. (2018). Bid-ask spread determination in the FX swap market: competition, collusion or a convention? *Journal of International Financial Markets, Institutions and Money*, *54*, 78–97. https://doi.org/10.1016/j.intfin.2017.08.001

Stenfors, A., & Lindo, D. (2018). Libor 1986–2021: The making and unmaking of 'the world's most important price. *Distinktion: Journal of Social Theory*, *19*(2), 170-192. https://doi.org/10.1080/1600910X.2018.1430599

Svensson, L. E. (1995). Estimating forward interest rates with the extended Nelson & Siegel method. *Quarterly Review. Sveriges Riksbank, 3*, 13-26.

The Association for Financial Markets in Europe, AFME. (2019). "IBOR Reform: What preparations do banks still need to make?" Conference on Benchmark Rate Reform: Association for Financial Markets in Europe. March 2019.

Upper, Ch. (2011). Simulation methods to assess the danger of contagion in interbank markets. BIS Working Paper no 234, Bank for International Settlements.

Upper, Ch., & Worms, A. (2004). Estimating bilateral exposures in the German interbank market: Is there a danger of contagion? *European Economic Review*, *48*(4), 827-49.

Vassallo, D., Lieven, H., &, Kostka, T. (2020). Volatility-targeting strategies and the market sell-off. European Central Bank, *Financial Stability Review*, 05/2020, 41-43.

Vaughan, L., & Finch, G. (2017). Libor scandal: The bankers who fixed the world's most important number. *The Guardian*, January 18.

Vivar, M. L., Wedow, M., & Weistroffer, Ch. (2020). Burned by leverage? Flows and fragility in bond mutual funds. *Working Paper Series*, *2413*. European Central Bank.

Volatility Lab, GARCH models documentation. https://vlab.stern.nyu.edu/docs

Wang, T., Zhao, S., Wang, W., & Yang, H. (2023). How Does Exogenous Shock Change the Structure of Interbank Network?: Evidence from China under COVID-19. *Emerging Markets Finance and Trade*, *59*(4), 937-958. https://doi.org/10.1080/1540496x.2022.2127315

Walesiak, M., & Dudek, A. (2016). *ClusterSim: Searching optimal clustering procedure for a data set*. R package version 0.45-1.

Wieczorek, D., Stachura, M., Wachecka-Kotkowska, L., Marks, L., Krzyszkowski, D., A., & Karaś, M. (2021). Similarities among glacials and interglacials in the LR04 benthic oxygen isotope stack over the last 1.014 million years revealed by cluster analysis and a DTW algorithm. *Global and Planetary Change* 202, 103521. https://doi.org/10.1016/j.gloplacha.2021.103521

Zawadowski, A. (2013). Entangled financial systems. *Review of Financial Studies, Society for Financial Studies*, *26*(5), 1291-1323.

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Appendix A

Table A1. LIBOR panel compositions by currency

Bank	USD	GBP	EUR	CHF	JPY
Bank of America NA (London Branch)	x				
Bank of Tokyo-Mitsubishi UFJ Ltd	x	x	x	X	X
Barclays Bank plc	x	x	x	X	X
BNP Paribas SA, London Branch	x	x			
Citibank N.A. (London Branch)	x	x	x	X	
Credit Agricole Corporate & Investment Bank	x	x			X
Credit Suisse AG (London Branch)	x		x	X	
Deutsche Bank AG (London Branch)	x	x	x	X	X
HSBC Bank plc	x	x	x	X	X
JPMorgan Chase Bank, NA. London Branch	x	x	x	X	X
Lloyds TSB Bank plc	x	x	x	X	X
Mizuho Bank, Ltd.		x	x		X
Rabobank Intl CCRB (Cooperatieve Centrale Raiffeisen – Boerenleenbank B.A.)	x	x	x		
Royal Bank of Canada	x	x	x		
Santander UK plc		x	x		
Société Générale (London Branch)	x	x	x	X	X
Sumitomo Mitsui Banking Corporation Europe Ltd	x				X
The Norinchukin Bank	x				X
The Royal Bank of Scotland plc	x	x	x	X	X
UBS AG	x	x	x	X	X

Source: Authors' elaboration.

Table A2. IBOR rates, ARR rates and IOS in analysed European countries

Country	IBOR	IBOR as RR since	ARR	OIS-market quota
EURO area	EURIBOR	1999	€STR	X
United Kingdom	LIBOR	1986	SONIA	X
Switzerland	LIBOR for CHF	1989	SARON	X
Sweden	STIBOR	1986	SWESTR	X
Denmark	CIBOR	1989	DESTR	X
Norway	NIBOR	1986	NOWA	
Iceland	REIBOR	1998	not decided yet	
Czechia	PRIBOR	1992	CZEONIA	X
Hungary	BUBOR	1996	HUFONIA	X
Poland	WIBOR	1993	WIRON	X
Bulgaria	SOFIBOR	2003	LEONIA plus	
Romania	ROBOR	1995	not decided yet	
Croatia	ZIBOR	1998	in EURO as of 2023	
Ukraine	KIEIBOR	2005	UONIA	
Slovakia	BRIBOR	1995	in EURO	
Lithuania	VILIBOR	1999	in EURO	
Latvia	RIGIBOR	1997	in EURO	
Estonia	TALIBOR	1996	in EURO	
Russia	MIBOR / MOSPRIME	1997	RUONIA	X

Source: Authors' elaboration.

Table A3. Systemically important banks used to model the banking systems

		Systemically important for																		
Country of residence	Bank identifier	Bulgaria	Croatia	Czechia	Denmark	Estonia	Eurozone	Hungary	Iceland	Latvia	Lithuania	Norway	Poland	Romania	Slovakia	Sweden	Switzerland	United Kingdom	Russia	Name of the bank
Austria	ADKO.VI		x				x													Addiko Bank
	ERST.VI		x	x			x	x						x	x					Erste Group Bank
	RBIV.VI	x	x	x			x	x						x	x					Raiffeisen Bank International
Belgium	KBC.BR	x		x			x	x							x					KBC Groep
Bulgaria	CCB.BB	x																		Central Cooperative Bank
	FIB.BB	x																		First Investment Bank
Croatia	HPBZ.ZA		x																	Hrvatska postanska banka
	ZBB.ZA		x																	Zagrebacka banka
Denmark	DANSKE.CO				x															Danske Bank
	JYSK.CO				x															Jyske Bank
	SPNO.CO				x															Spar Nord Bank
	SYDB.CO				x															Sydbank
France	BNPP.PA						x													BNP Paribas
	CAGR.PA						x													Credit Agricole
	SOGN.PA	x	x	x			x													Societe Generale
Germany	CBKG.DE						x													Commerzbank
	DB1Gn.DE						x													Deutsche Boerse
	DBKGn.DE						x													Deutsche Bank
Greece	ACBr.AT						x							x						Alpha Services and Holdings
	BOPr.AT	x					x													Piraeus Financial Holdings
	EURBr.AT	x					x							x						Eurobank Ergasias Services and Holdings
	NBGr.AT						x													National Bank of Greece
Hungary	OTPB.BU	x	x					x						x						OTP Bank Nyrt
Iceland	ARION.IC								x											Arion banki
	ISB.IC								x											Islandsbanki
Italy	CRDI.MI	x		x				x						x						UniCredit
	ISP.MI		x					x							x					Intesa Sanpaolo
Japan	8604.T																	x		Nomura Holdings
Lithuania	SAB1L.VL										x									Siauliu bankas
Malta	APSA.MT						x													APS Bank
	BOV.MT						x													Bank of Valletta
	FIM.MT						x													FIMBank
	HSB.MT						x													HSBC Bank Malta
Netherlands	ABNd.AS						x													ABN Amro Bank
	INGA.AS						x													ING Groep

Norway	DNB.OL					x					x	x								DNB BANK ASA
Poland	BHW.WA												x							Bank Handlowy w Warszawie
	BNP1.WA												x							BNP Paribas Bank Polska
	INGP.WA												x							ING Bank Slaski
	MBK.WA												x							mBank
	MILP.WA												x							Bank Millennium
	PEO.WA												x							Bank Polska Kasa Opieki
	PKO.WA												x							Powszechna Kasa Oszczednosci Bank Polski
	SPL1.WA												x							Santander Bank Polska
Portugal	BCP.LS						x													Banco Comercial Portugues
Romania	ROBRD.BX													x						BRD Groupe Societe Generale
	ROTLV.BX													x						Banca Transilvania
Slovenia	NLBR.LJ						x													Nova Ljubljanska Banka
Spain	BBVA.MC						x													Banco Bilbao Vizcaya Argentaria
	CABK.MC						x													Caixabank
	SABE.MC						x													Banco de Sabadell
	SAN.MC						x											x		Banco Santander
Sweden	NDASE.ST				x	x					x	x				x				Nordea Bank
	SEBa.ST					x				X	x					x				Skandinaviska Enskilda Banken
	SHBa.ST															x				Svenska Handelsbanken
	SWEDa.ST					x				X	x					x				Swedbank
Switzerland	CSGN.S																x	x		Credit Suisse Group
	UBSG.S																x			UBS Group
Turkey	GARAN.IS													x						Turkiye Garanti Bankasi
United Kingdom	BARC.L																	x		Barclays
	HSBA.L																	x		HSBC Holdings
	LLOY.L																	x		Lloyds Banking Group
	NBS.L																	x		Nationwide Building Society
	NWG.L																	x		NatWest Group
	STAN.L																	x		Standard Chartered
USA	BAC																	x		Bank of America Corporation
	C																	x		Citigroup
	GS																	x		The Goldman Sachs Group
	JPM																	x		JPMorgan Chase & Co.
	MS																	x		Morgan Stanley
Russia	SBER.MM																		x	Sberbank Rossii
	VTBR.MM																		x	Bank VTB

Source: Authors' elaboration.

Table A4. Kendall correlation coefficients

	Bulgaria	Croatia	Czechia	Denmark	Estonia	Euro	Hungary	Iceland	Latvia	Lithuania	Norway	Poland	Romania	Slovakia	Sweden	Switzerland	UK	Ukraine
Croatia	.13																	
Czechia	-.01	.25																
Denmark	-.06	-.02	.05															
Estonia	.04	.34	.25	-.01														
Euro	.07	.24	.20	-.02	.69													
Hungary	.02	.15	.11	.05	.08	.06												
Iceland	.10	.21	.12	.01	.15	.05	.04											
Latvia	.05	.40	.23	.02	.67	.53	.05	.23										
Lithuania	.14	.18	.12	-.04	.46	.49	.02	.00	.40									
Norway	.24	.05	.10	.00	.17	.31	.05	.01	.07	.14								
Poland	.11	.18	.20	.21	.27	.15	.08	.19	.26	.10	.09							
Romania	.12	.30	.15	.09	.21	.14	.08	.32	.26	.04	.12	.25						
Slovakia	-.08	.27	.22	-.02	.72	.81	.08	.06	.56	.44	.14	.15	.16					
Sweden	.11	-.02	.12	.14	.11	.18	.02	-.02	.04	.10	.35	.17	.03	.11				
Switzerland	.10	.23	.23	.02	.28	.24	.07	-.03	.23	.26	.27	.17	.00	.22	.18			
UK	.04	-.02	.03	.14	-.04	.06	-.05	-.04	-.06	.01	.20	.05	-.03	.04	.17	.13		
Ukraine	.17	.29	.14	-.06	.22	.17	.11	.25	.27	.02	.19	.15	.35	.17	.00	-.03	-.11	
Russia	.26	.03	-.04	-.10	.07	.11	.07	.05	.04	.07	.15	.02	.11	.08	.01	.06	-.02	.15

Source: Authors' calculations.

Table A5. Ranking of markets based on volatility of turbulence in seven sub-periods

Period	I	II	III	IV	V	VI	VII
Bulgaria	2	16	17	13			
Croatia	17	17	16	12	10		
Czechia	11	7	6	2	5	4	3
Denmark	7	1	2	7	1	2	4
Estonia	15	11	13				
Euro	5	5	4	5	3	12	6
Hungary	8	8	8	9	6	10	9
Iceland	13	13	9	10	9	1	2
Latvia	16	14	15				
Lithuania	6	10	11	4			
Norway	9	12	10				
Poland	10	6	7	8	4	3	5
Romania	19	15	14	11	11	5	7
Slovakia	14	9					
Sweden	3	4	5	6	8	7	8
Switzerland	1	3	1	3	2	6	
Ukraine	18	19	18	15	13	11	
UK	4	2	3	1	7	8	1
Russia	12	18	12	14	12	9	

Source: Authors' calculations.

Table A6. Ranking of markets based on level of turbulence in seven subperiods

Period	I	II	III	IV	V		VI	VII
Bulgaria	1	15	15	12				
Croatia	18	18	17	13	9			
Czechia	13	9	9	8	4		8	7
Denmark	7	1	4	4	3		2	3
Estonia	12	11	10					
Euro	6	6	3	5	1		7	4
Hungary	9	8	8	9	7		10	9
Iceland	14	12	14	10	10		4	2
Latvia	16	14	13					
Lithuania	3	5	5	3				
Norway	11	13	12					
Poland	8	7	7	6	5		1	5
Romania	17	16	16	14	12		3	6
Slovakia	15	10						
Sweden	2	4	6	7	8		5	8
Switzerland	5	3	2	1	2		9	
Ukraine	19	19	18	15	13		12	
UK	4	2	1	2	6		6	1
Russia	10	17	11	11	11		11	

Source: Authors' calculations.

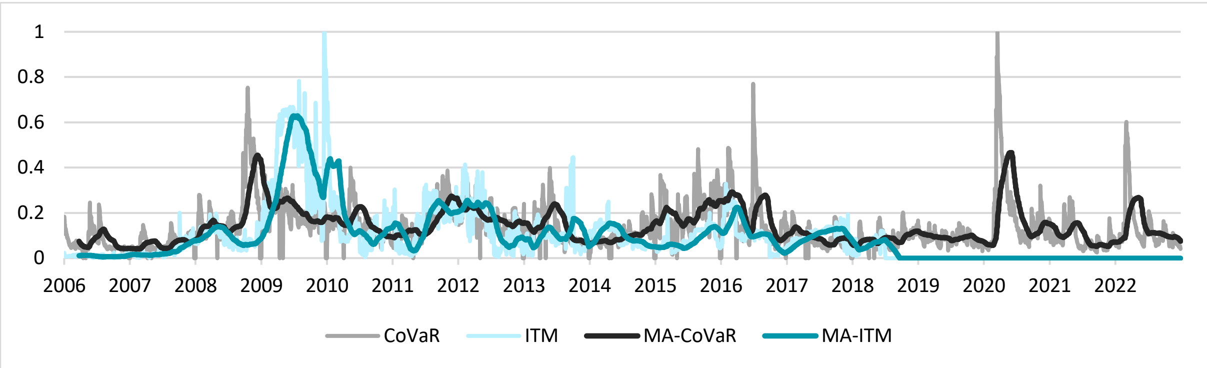

Fig. A1. Comparison of ITM and CoVaR for Bulgaria

Source: Authors' calculations.

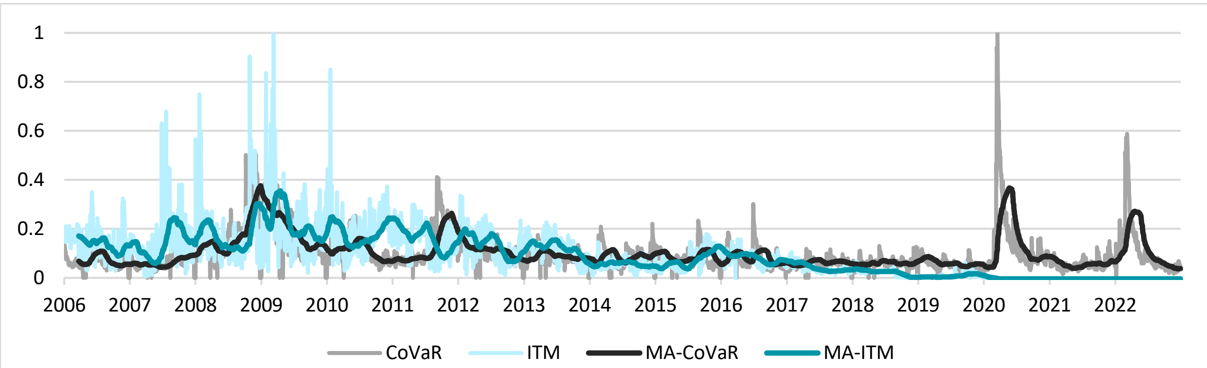

Fig. A2. Comparison of ITM and CoVaR for Croatia

Source: Authors' calculations.

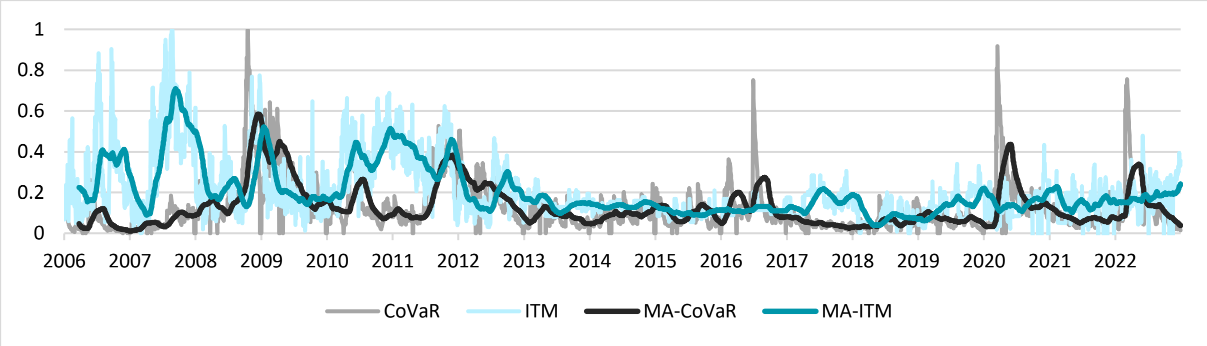

Fig. A3. Comparison of ITM and CoVaR for Czechia

Source: Authors' calculations.

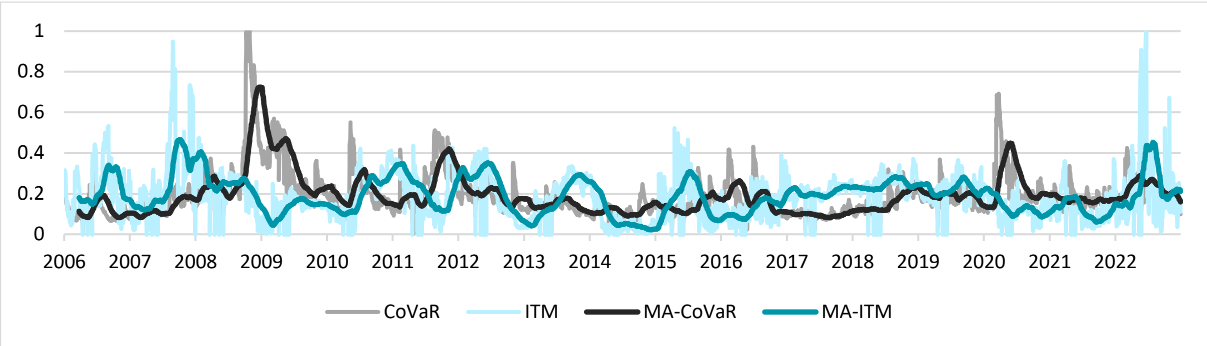

Fig. A4. Comparison of ITM and CoVaR for Denmark

Source: Authors' calculations.

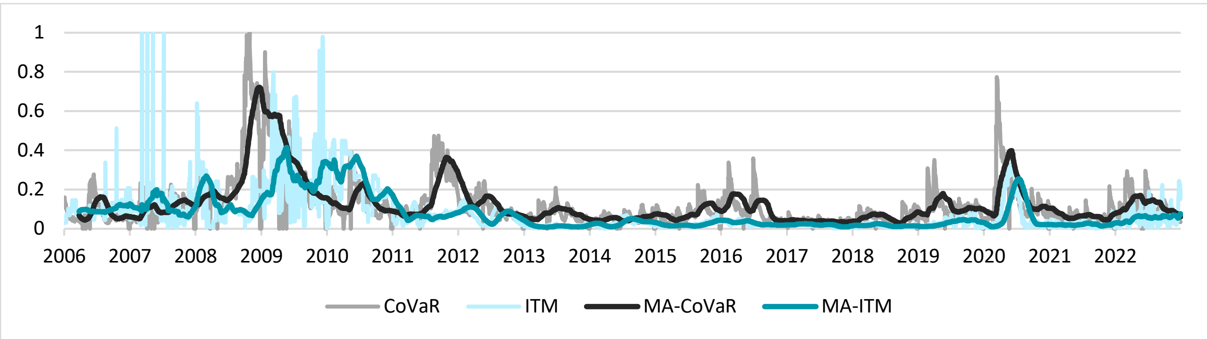

Fig. A5. Comparison of ITM and CoVaR for Estonia

Source: Authors' calculations.

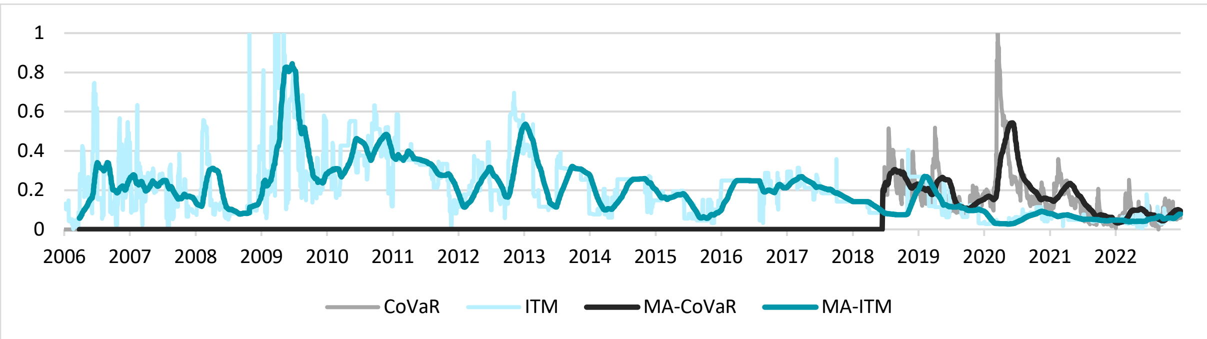

Fig. A6. Comparison of ITM and CoVaR for Iceland

Source: Authors' calculations.

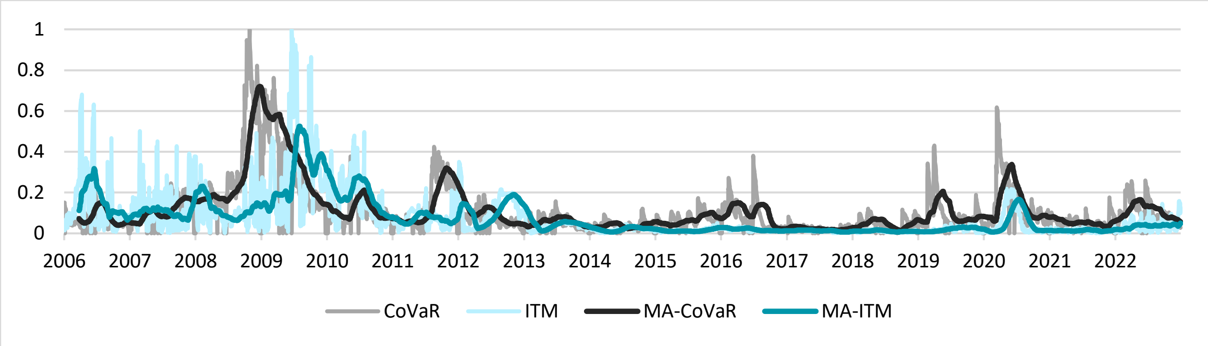

Fig. A7. Comparison of ITM and CoVaR for Latvia

Source: Authors' calculations.

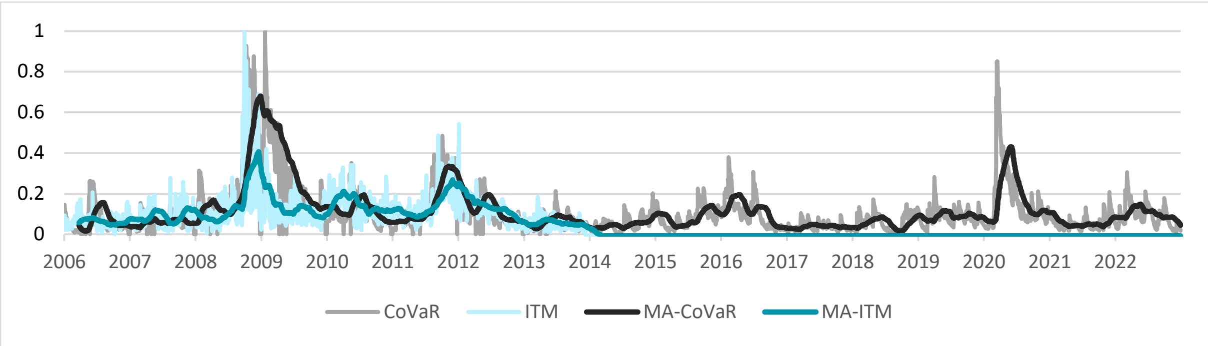

Fig. A8. Comparison of ITM and CoVaR for Norway

Source: Authors' calculations.

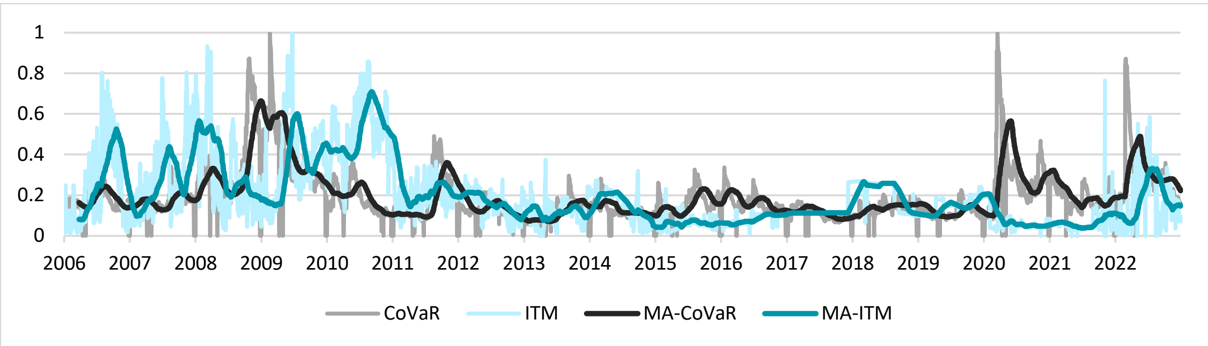

Fig. A9. Comparison of ITM and CoVaR for Poland

Source: Authors' calculations.

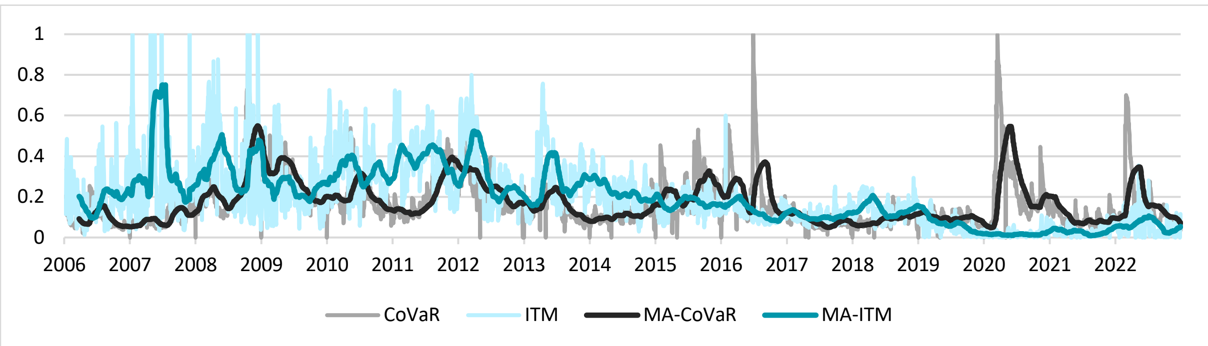

Fig. A10. Comparison of ITM and CoVaR for Romania

Source: Authors' calculations.

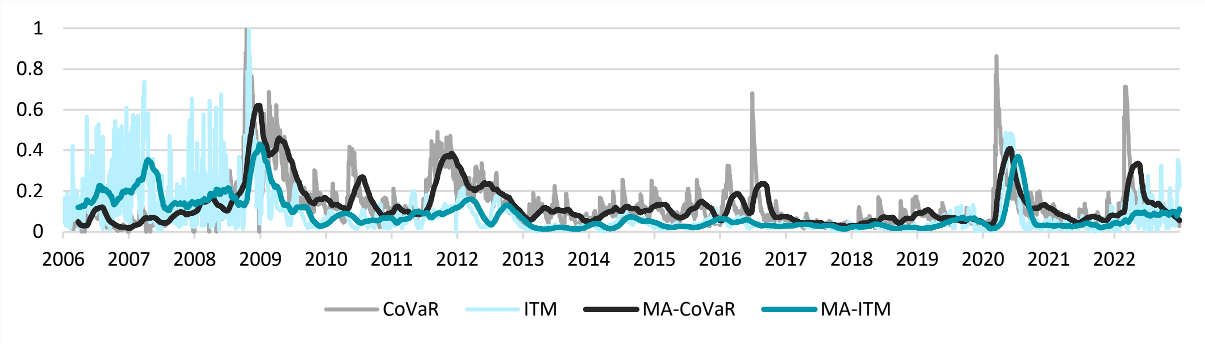

Fig. A11. Comparison of ITM and CoVaR for Slovakia

Source: Authors' calculations.

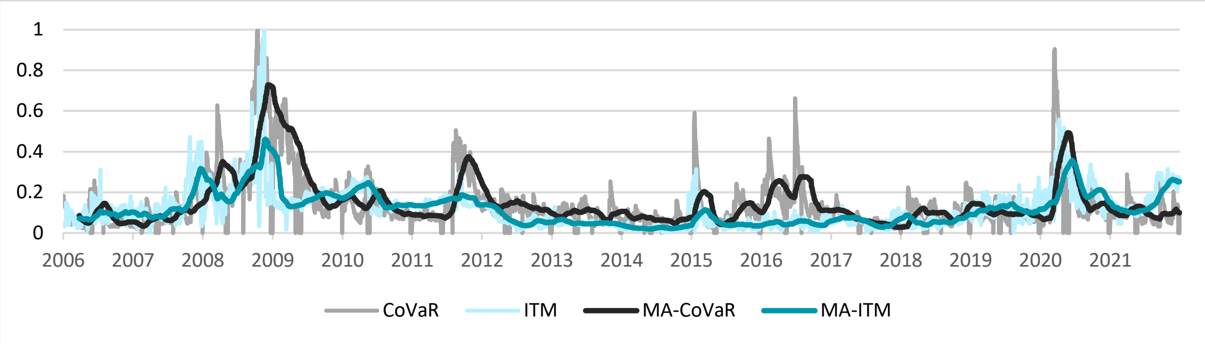

Fig. A12. Comparison of ITM and CoVaR for Switzerland

Source: Authors' calculations.

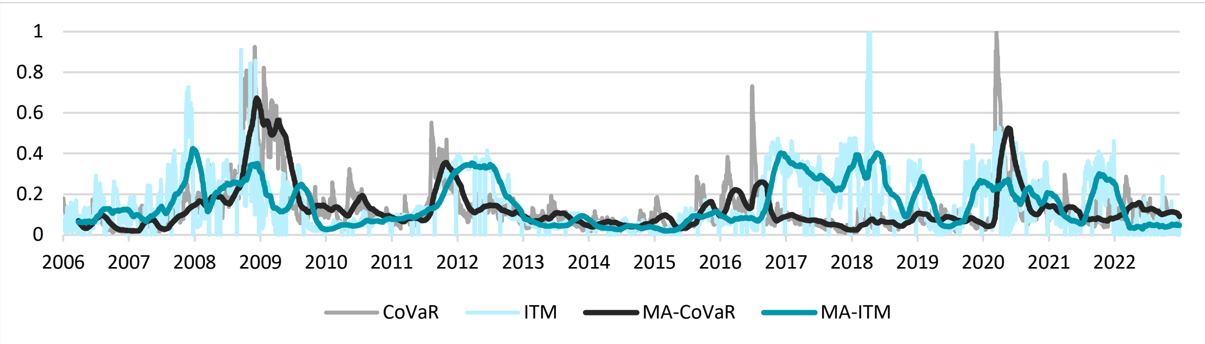

Fig. A13. Comparison of ITM and CoVaR for the United Kingdom

Source: Authors' calculations.

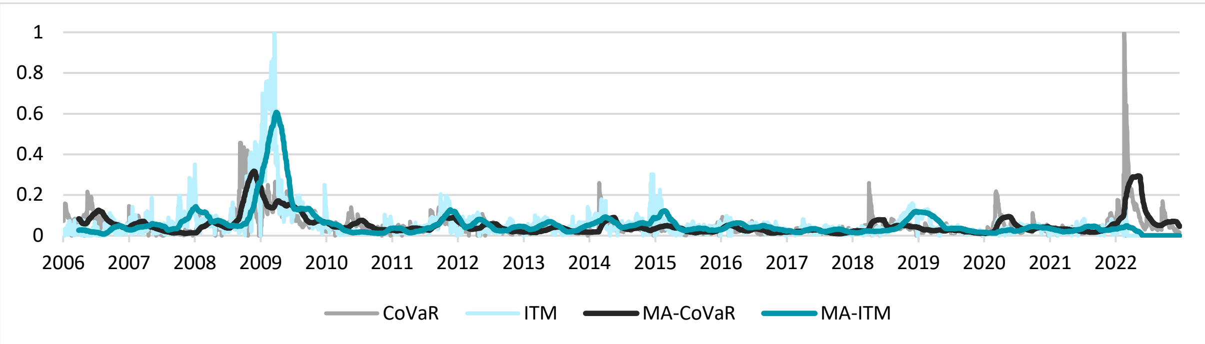

Fig. A14. Comparison of ITM and CoVaR for Russia

Source: Authors' calculations.

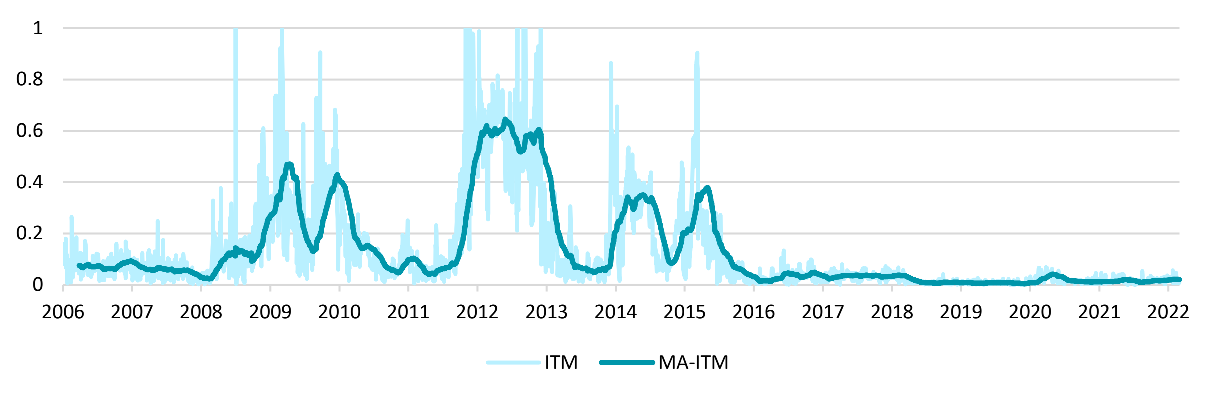

Fig. A15. ITM for Ukraine

Source: Authors' calculations.

Appendix B

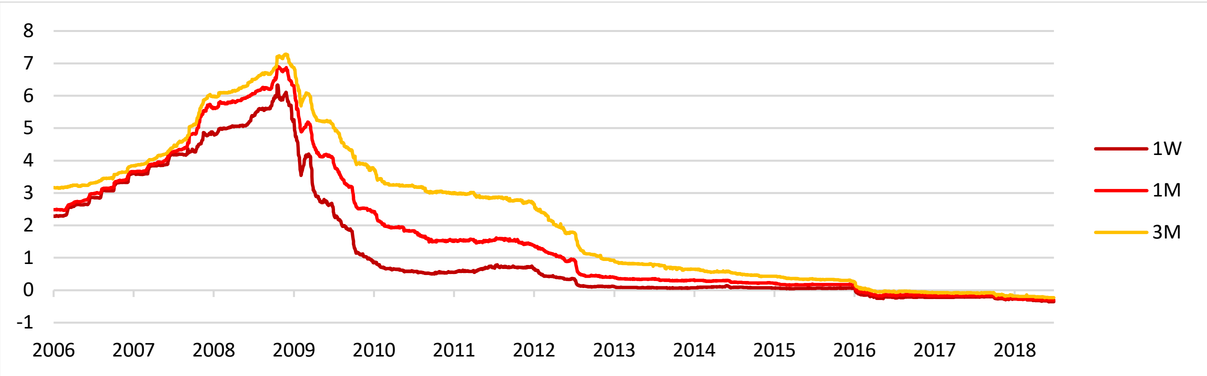

Fig. B1. Term structure of IBOR rates in Bulgaria

Source: Authors' calculations.

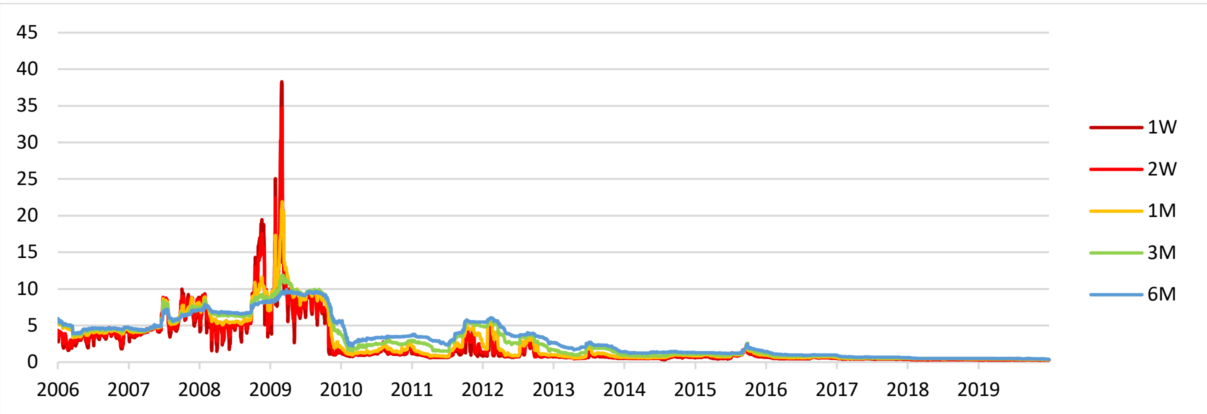

Fig. B2. Term structure of IBOR rates in Croatia

Source: Authors' calculations.

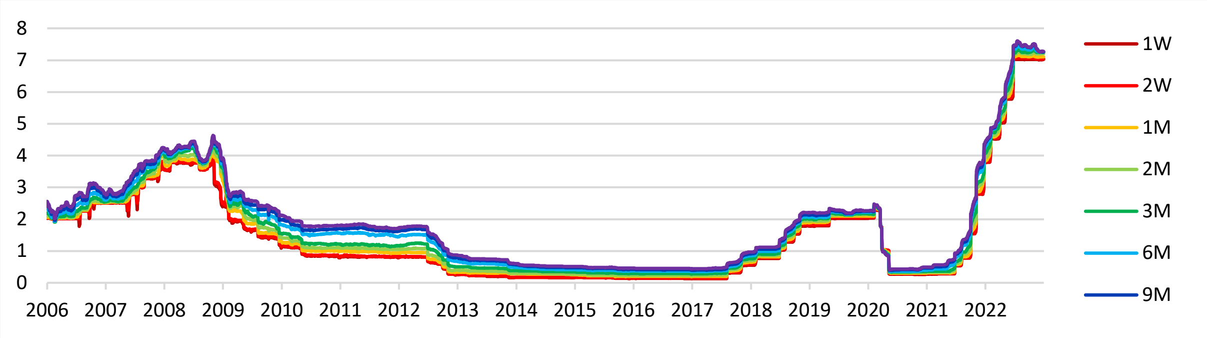

Fig. B3. Term structure of IBOR rates in Czechia

Source: Authors' calculations.

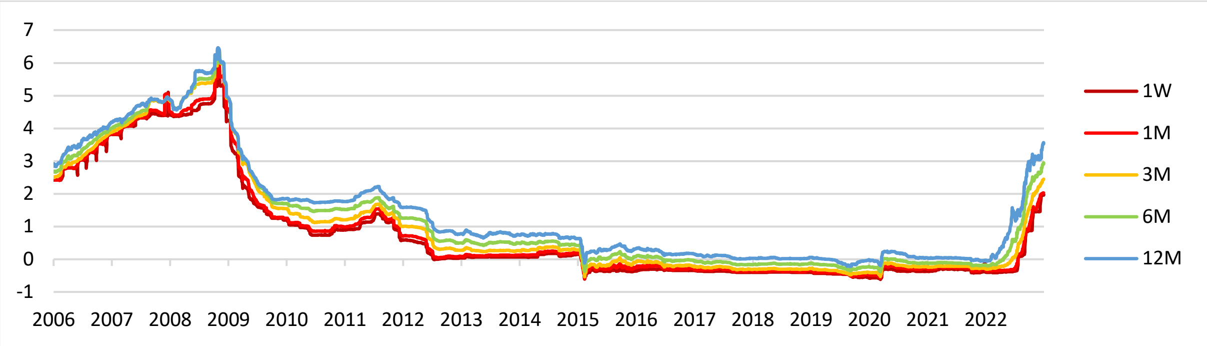

Fig. B4. Term structure of IBOR rates in Denmark

Source: Authors' calculations.

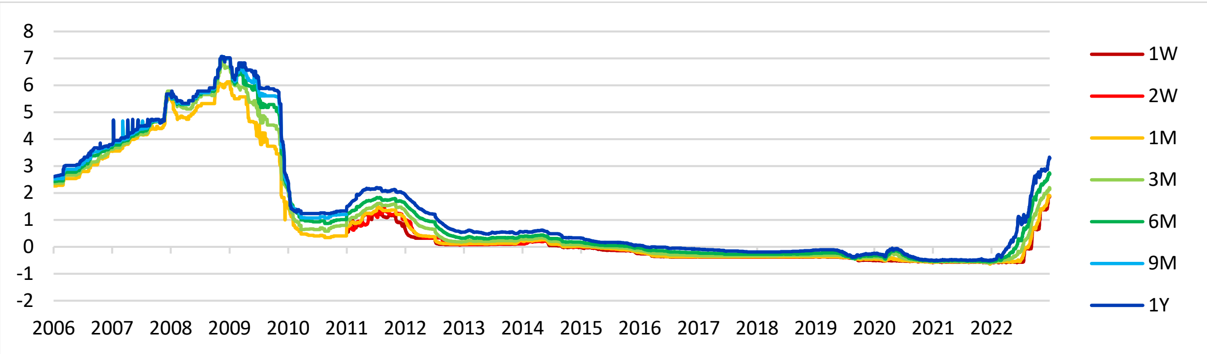

Fig. B5. Term structure of IBOR rates in Estonia

Source: Authors' calculations.

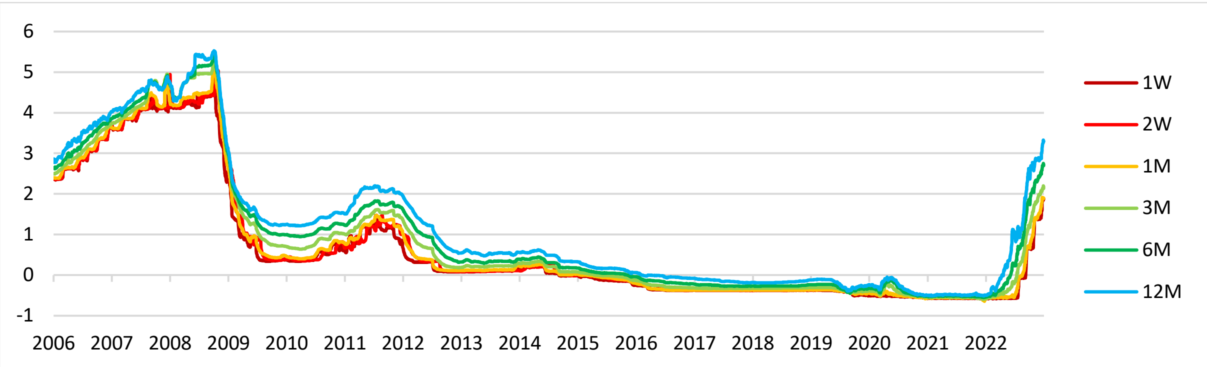

Fig. B6. Term structure of IBOR rates in the Eurozone

Source: Authors' calculations.

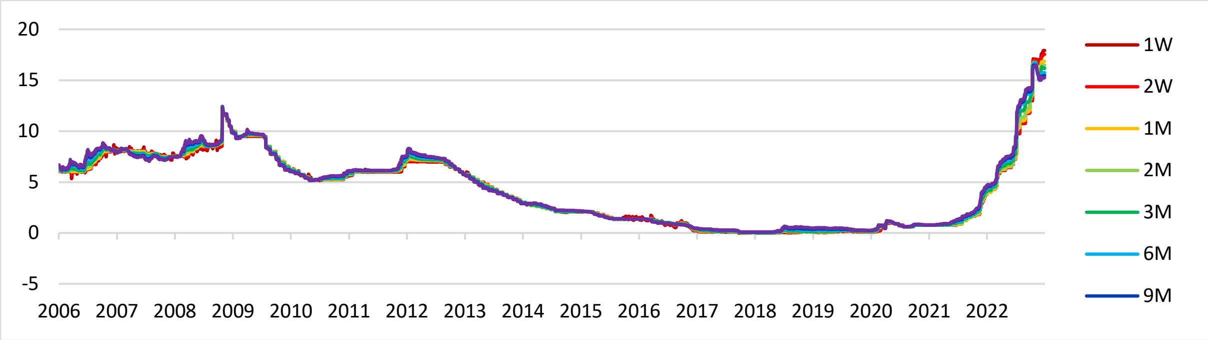

Fig. B7. Term structure of IBOR rates in Hungary

Source: Authors' calculations.

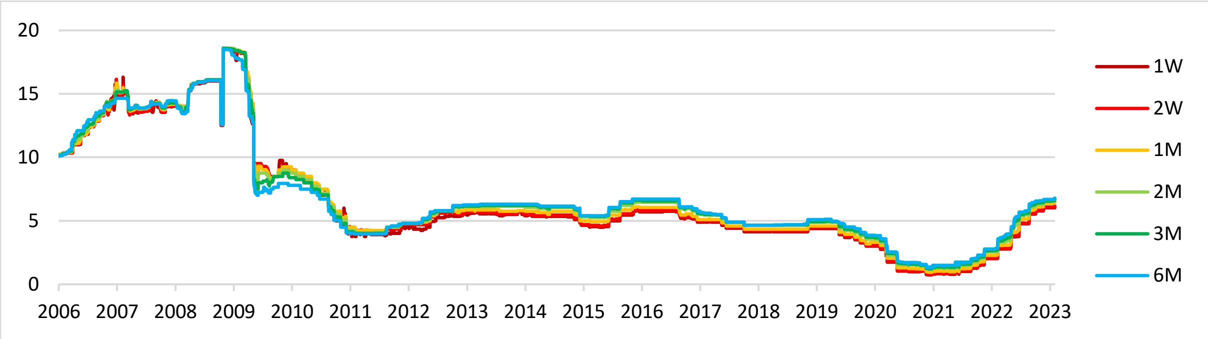

Fig. B8. Term structure of IBOR rates in Iceland

Source: Authors' calculations.

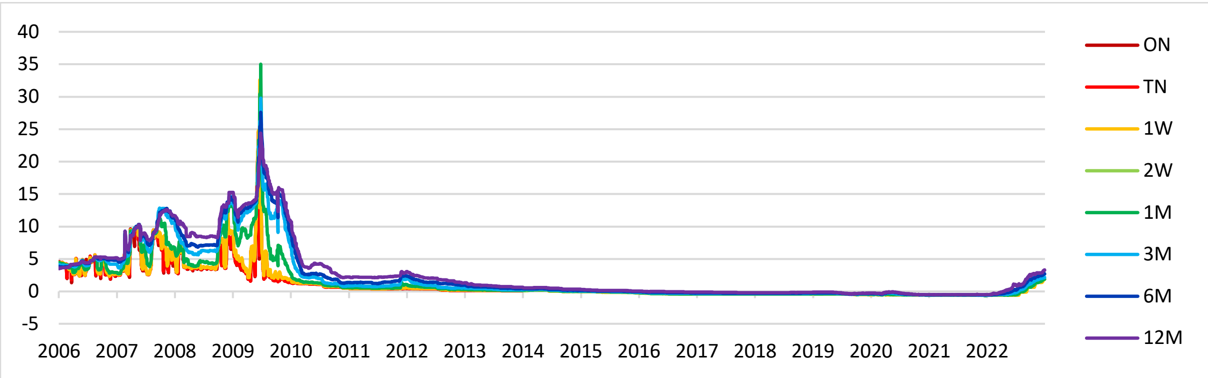

Fig. B9. Term structure of IBOR rates in Latvia

Source: Authors' calculations.

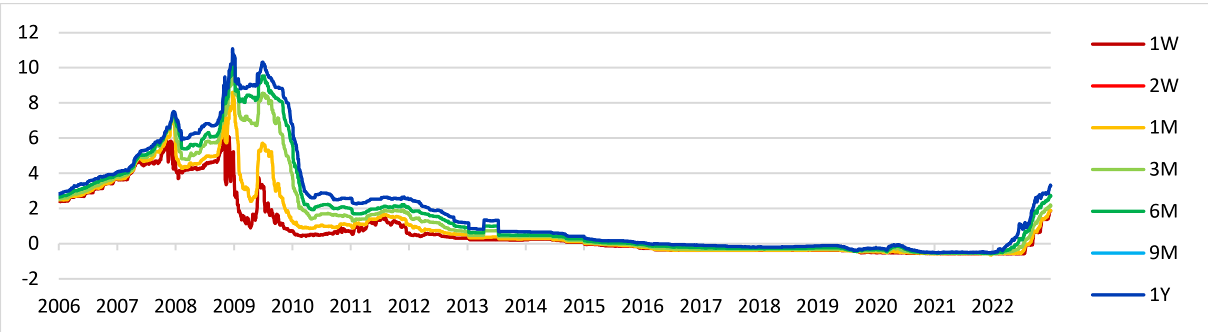

Fig. B10. Term structure of IBOR rates in Lithuania

Source: Authors' calculations.

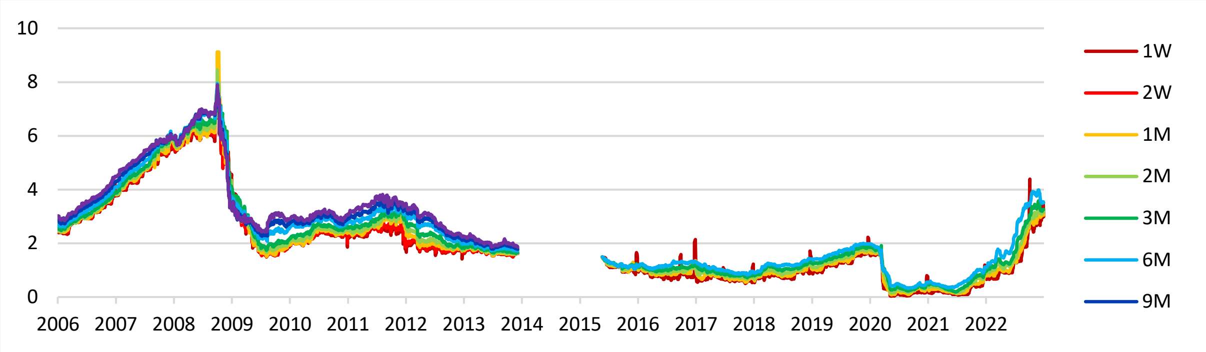

Fig. B11. Term structure of IBOR rates in Norway

Source: Authors' calculations.

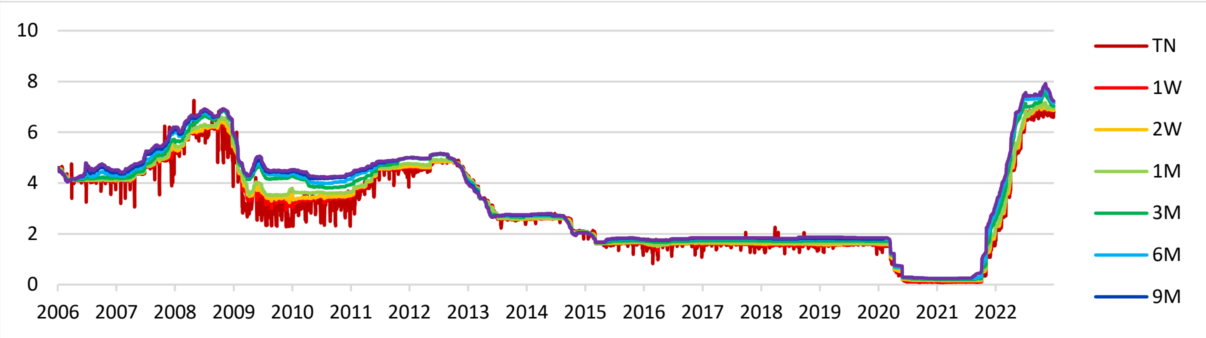

Fig. B12. Term structure of IBOR rates in Poland

Source: Authors' calculations.

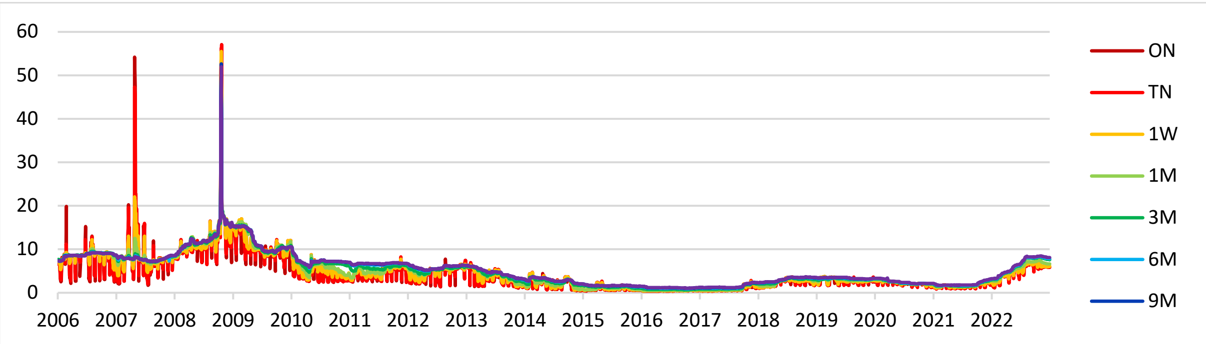

Fig. B13. Term structure of IBOR rates in Romania

Source: Authors' calculations.

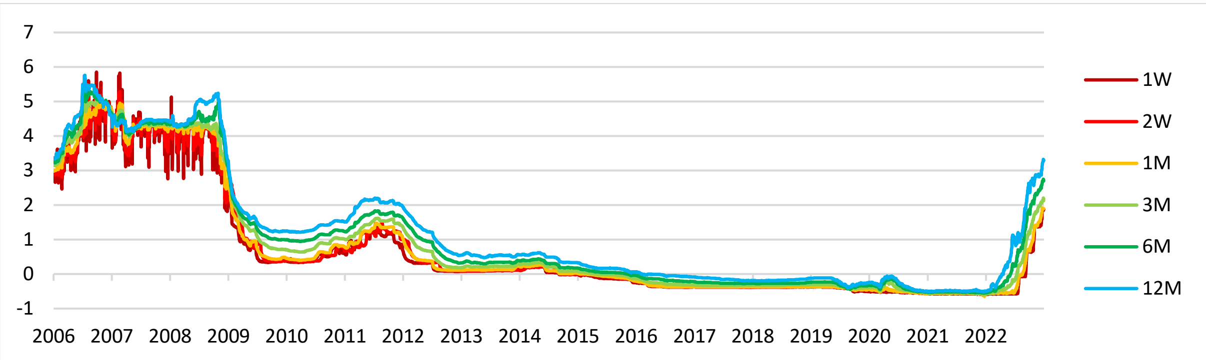

Fig. B14. Term structure of IBOR rates in Slovakia

Source: Authors' calculations.

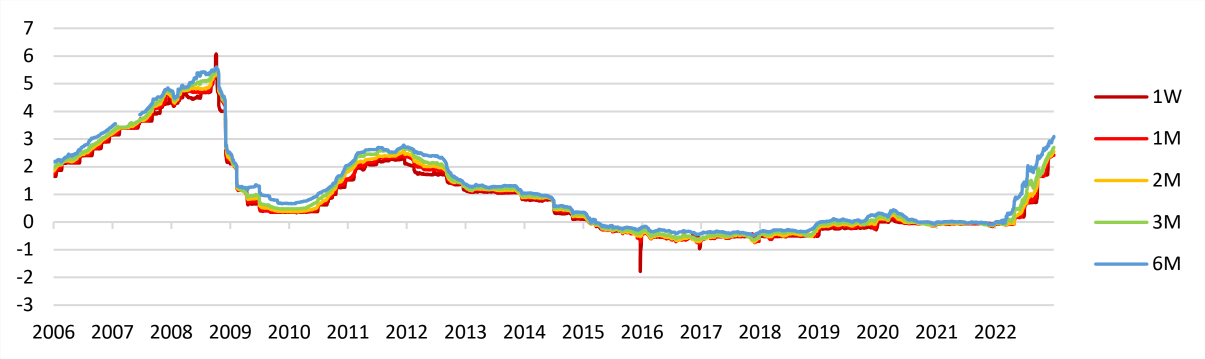

Fig. B15. Term structure of IBOR rates in Sweden

Source: Authors' calculations.

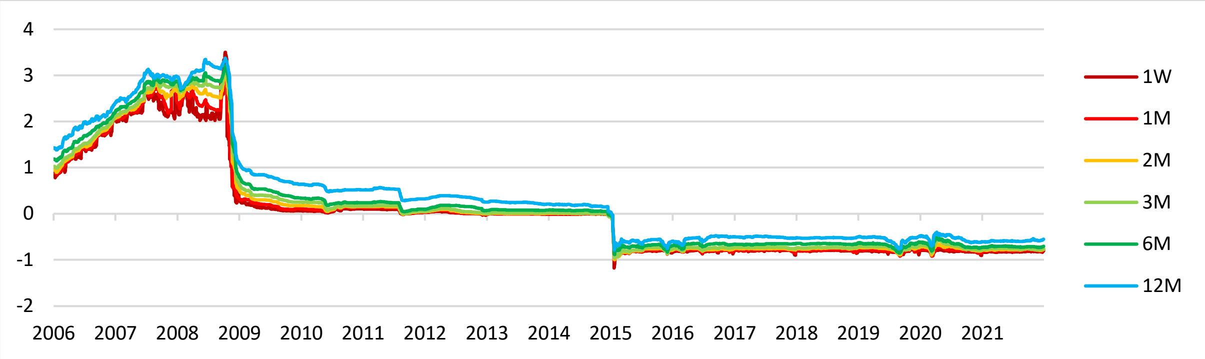

Fig. B16. Term structure of IBOR rates in Switzerland

Source: Authors' calculations.

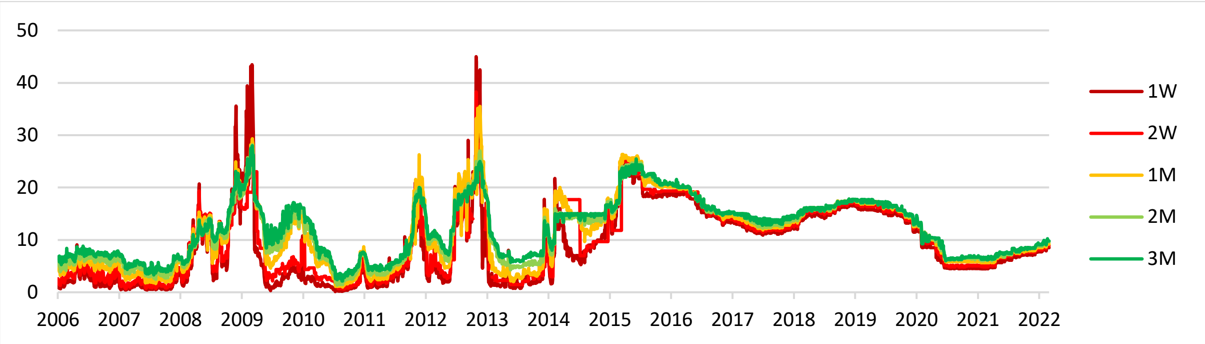

Fig. B17. Term structure of IBOR rates in Ukraine

Source: Authors' calculations.

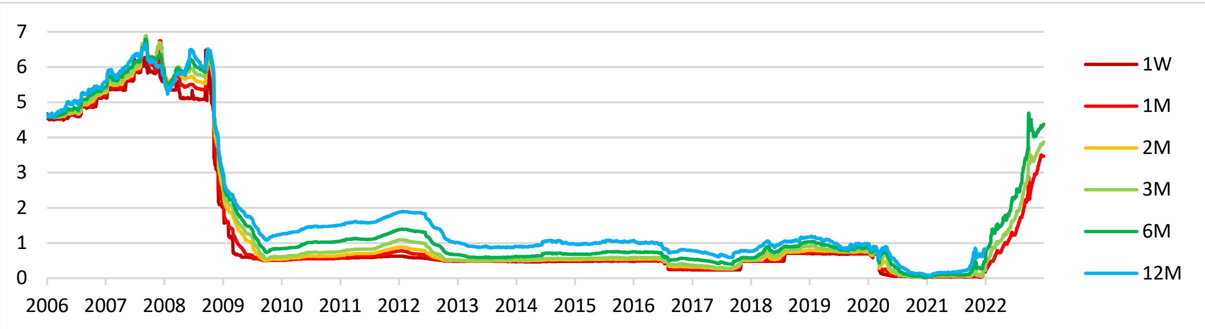

Fig. B18. Term structure of IBOR rates in the United Kingdom

Source: Authors' calculations.

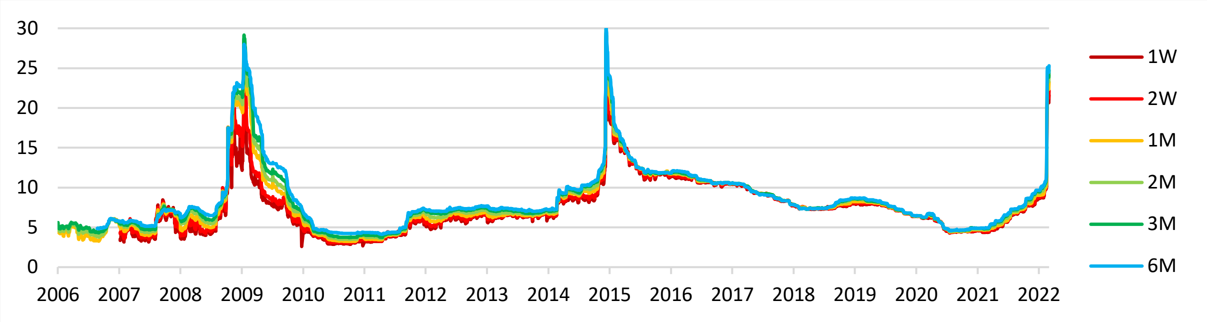

Fig. B19. Term structure of IBOR rates in Russia

Source: Authors' calculations.

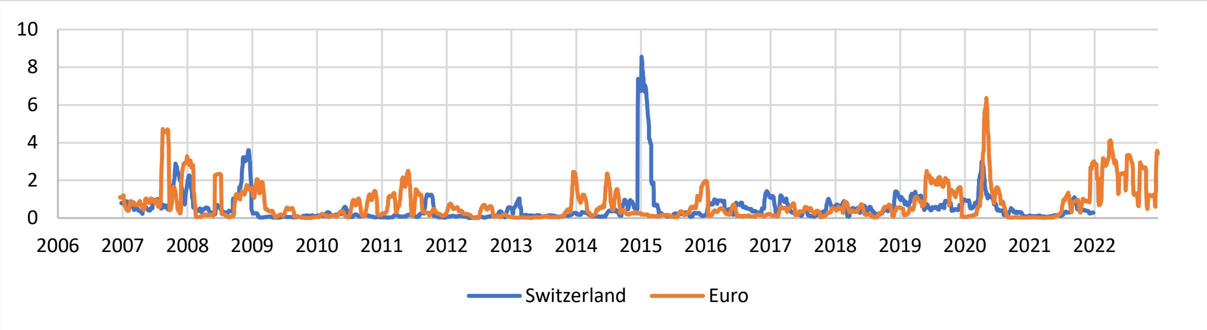

Fig. B20. Comparison of moving coefficients of variation of ITM – Switzerland vs. the Eurozone

Source: Authors' calculations.

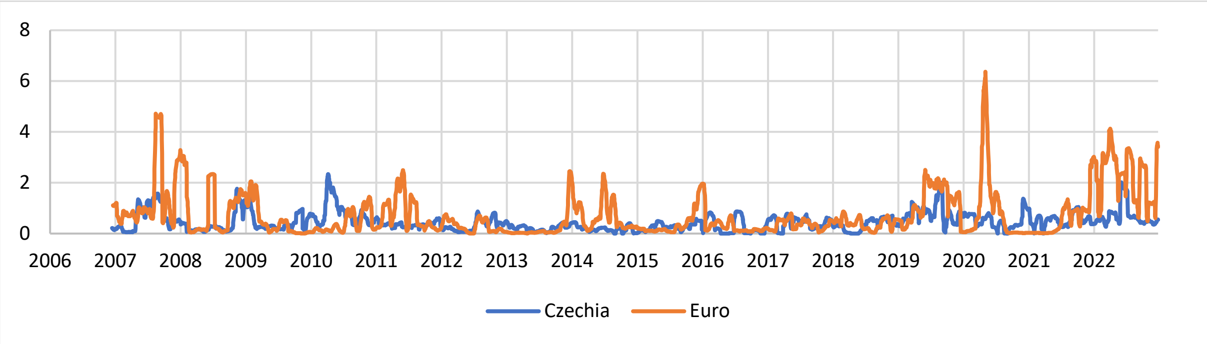

Fig. B21. Comparison of moving coefficients of variation of ITM – Czechia vs. the Eurozone

Source: Authors' calculations.

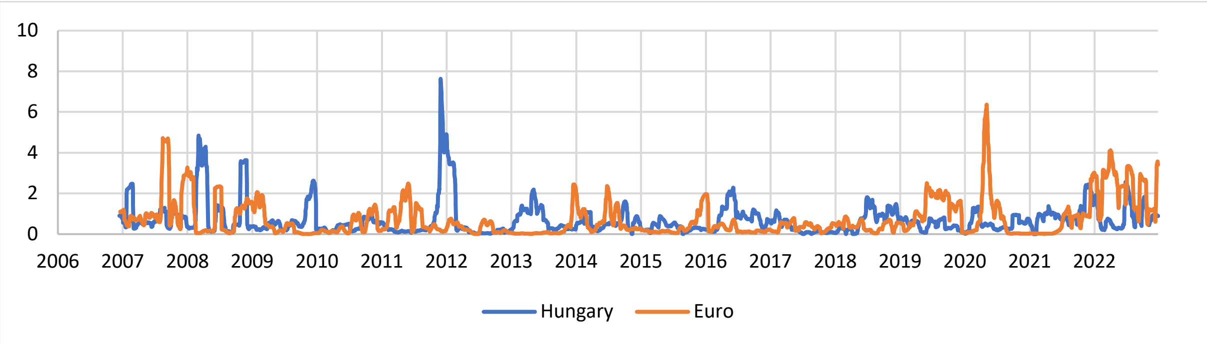

Fig. B22. Comparison of moving coefficients of variation of ITM – Hungary vs. the Eurozone

Source: Authors' calculations.

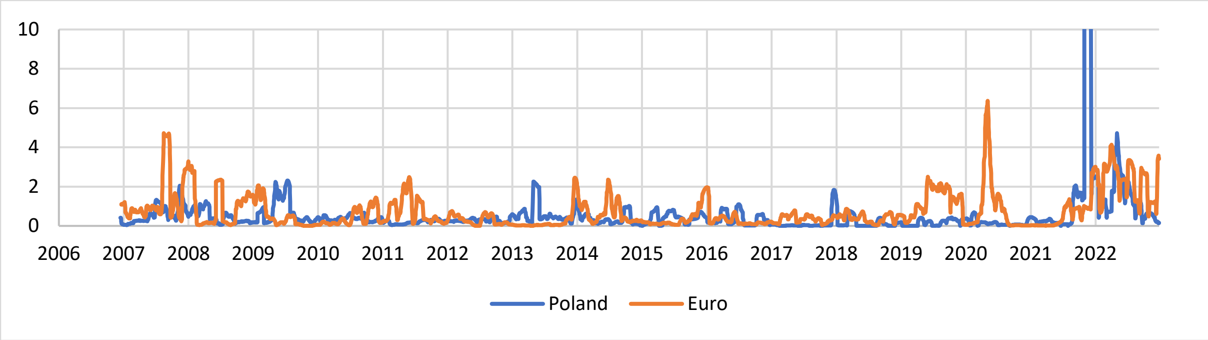

Fig. B23. Comparison of moving coefficients of variation of ITM – Poland vs. the Eurozone

Source: Authors' calculations.

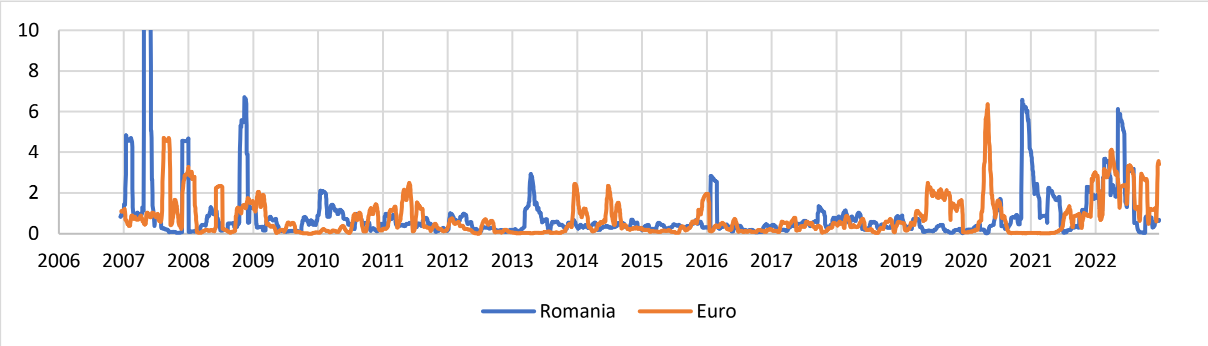

Fig. B24. Comparison of moving coefficients of variation of ITM – Romania vs. the Eurozone

Source: Authors' calculations.

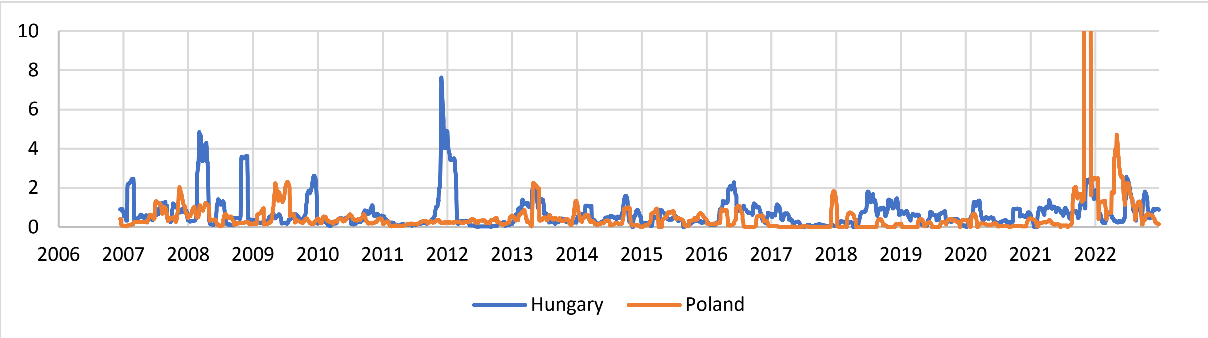

Fig. B25. Comparison of moving coefficients of variation of ITM – Hungary vs. Poland

Source: Authors' calculations.

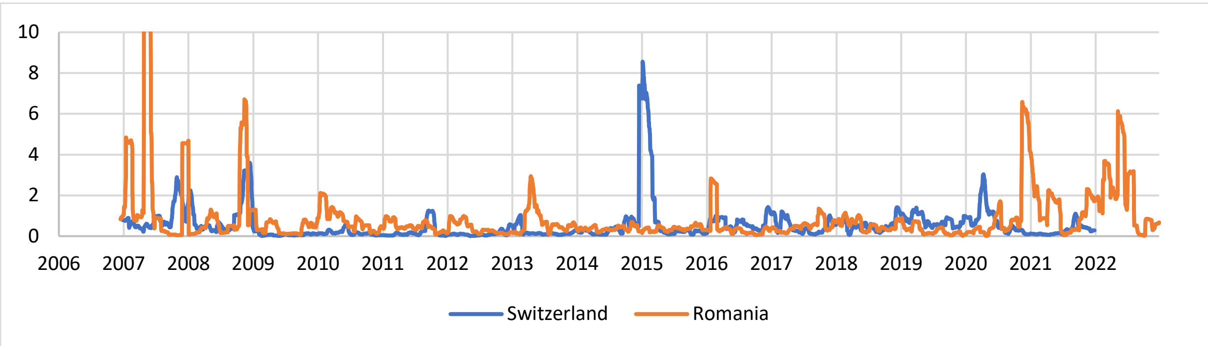

Fig. B26. Comparison of moving coefficients of variation of ITM – Switzerland vs. Romania

Source: Authors' calculations.

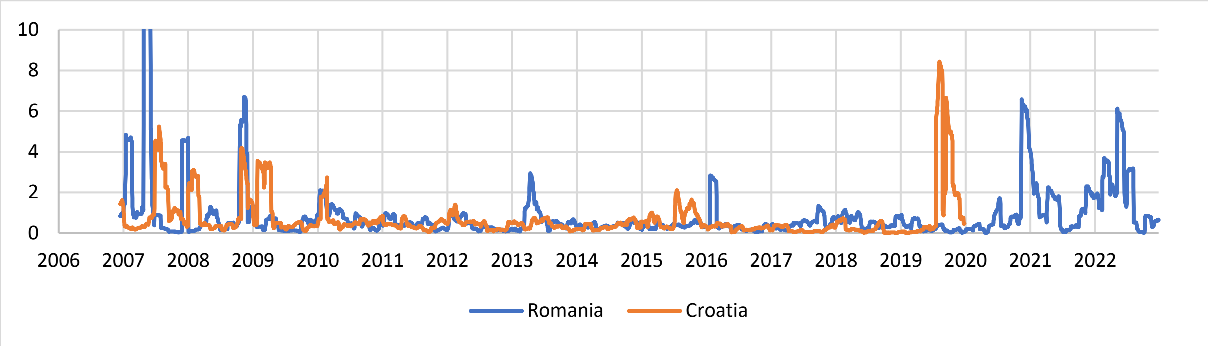

Fig. B27. Comparison of moving coefficients of variation of ITM – Romania vs. Croatia

Source: Authors' calculations.

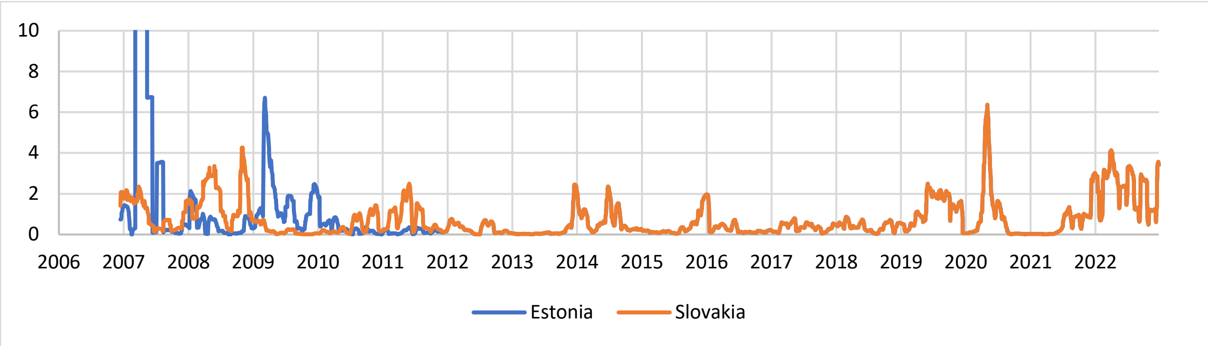

Fig. B28. Comparison of moving coefficients of variation of ITM – Estonia vs. Slovakia

Source: Authors' calculations.