ERASMUS UNIVERSITY ROTTERDAM

Erasmus School of Economics

Master Thesis Financial Economics

Interest Rate Risk in Times of Geopolitical Turbulence

A Study of Geopolitical Risk in Sovereign Bonds and Interest Rate Swaps using Panel VECM analysis

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Abstract

This thesis investigates the short-run relationship between geopolitical risk and both sovereign bond yields and interest rate swaps across 45 economies and 23 currency areas, covering the period 1990 to 2022. Panel vector error correction models are constructed to examine Granger causality with global and country-specific geopolitical risk indexes, as proposed by Matteo and Iacoviello (2022). The findings suggest a positive relationship between geopolitical risk and both bond yields and interest rate swaps, while emphasizing the importance of country-specific geopolitical risk indexes.

Keywords: geopolitical risk, VECM, bond, interest rate swap

Contents

1. Introduction

1.1 Research question

The role of geopolitical risk in financial markets has drawn the attention of financial market participants in recent years. Adverse geopolitical events seem to have sparked a shift to *reshoring* and potential deglobalization (ING, 2022). Interstate conflict is now perceived as a top 5 risk in 28 countries across the world (World Economic Forum, 2023). In response to increased uncertainty in the global political landscape, financial leaders are seeking to better understand the impact of geopolitical risk on financial market variables (McKinsey & Company, 2022).

Despite this interest, geopolitical risks have been difficult to quantify, making it hard to determine their impact on the valuation of financial products. Nevertheless, Caldara and Iacoviello (2022) have proposed a news-based geopolitical risk index (GPR) that provides an opportunity to explore the impact of this risk factor on the economy. The authors find that the GPR index can explain why investment is relatively low in industries and firms that are particularly exposed to geopolitical risk. Furthermore, the GPR index has been associated with inflationary effects (Caldara et al., 2022), which is attributed to fiscal policy as a channel of transmission. The impact of this factor on aggregate demand can, in turn, alter the equilibrium interest rate (Hicks, 1937).

Provided the connection between interest rates and inflation, the response of market interest rates to geopolitical turbulence is important to consider. Interest rates play a crucial role in pricing various forms of financial products, and thus the connection with geopolitical risk can have widespread implications. Sovereign bond markets seem naturally related to state-related tensions, while interest rate swaps (IRS) play a central role in interest rate risk management of financial institutions and institutional investors. Recent geopolitical events in a period of rising price levels have demonstrated that fiscal measures can have an impact on both IRS and government bond markets, as evidenced by the pension fund crisis in the UK (Financial Times, 2022). Therefore, this study seeks to investigate the effect of the GPR index on government bond and IRS markets across the 45 largest economies and 23 currency areas. This leads to the following research question:

How are government bonds and plain vanilla interest rate swaps across the 45 largest economies and 23 currency areas related to geopolitical risk in the short run in the period 1990-2022?

1.2 Relevance

The threat or realization of geopolitical events can cause market uncertainty, which is often measured by the Chicago Board Option Exchange's Market Volatility Index (VIX) (Whaley, 1993). By the application of the GPR index, this thesis builds on existing literature as to measurement of risk with news-based indexes. Engle et al. (2020) find that news-based indexes can be useful for risk management purposes in building *hedge portfolios*. The GPR index is relatively new and is defined more narrowly than other news-based indexes in the literature, such as the Economic Policy Uncertainty (EPU) index (Baker, Bloom & Davis, 2016) and the political risk index by Hassan et al. (2019). While these indexes consider a wider range of policy-related events, such as elections and fiscal policy debates, the GPR index specifically relates to tensions in international relations between countries. Hence, the analysis of the GPR index will have different implications for financial market participants.

The relationship of geopolitical risk with interest rates is examined in a model with several macroeconomic variables, as per the approach by Caldara and Iacoviello (2022), which will provide broader economic insights on the interaction of these variables. Forbes and Warnock (2012) connect higher economic uncertainty to capital flights and exchange rate (ER) shocks, Clarida, Gali and Gertler (1998) relate short-run expectations of inflation to forward-looking central banking policies, and Caldara et al. (2019) point out the role of aggregate demand and supply for the connection of geopolitical risk with the economy. Section 3 provides a description of these related theories and constructs corresponding hypotheses.

The GPR index has only recently been published by Caldara and Iacoviello (2022) and as a result many areas of application remain unexplored. Caldara et al. (2022) have looked into its application for examining inflation, and this thesis expands on this area of interest by examining interest rate markets. Besides, while both Caldara and Iacoviello (2022) and Caldara et al. (2022) apply vector autoregressive (VAR) models to analyze investment and inflation, this thesis deviates from the literature by employing restricted panel vector error correction models (VECM) in a monthly panel of 45 economies and 23 currency areas. To examine the geographical characteristics of GPR indexes, the performance of country-specific indexes is studied in regionally and geopolitically connected sub-groups. Additionally, the data in this thesis ranges from 1990 to December 2022, allowing for the inclusion of recent and major geopolitical conflicts in the sample.

1.3 Summary

The findings in this thesis are relevant for financial market participants, policymakers, and investors. Granger causality tests suggest that geopolitical risk, as measured by the GPR index, can have a significant short-term effect on both bond yields and IRS rates in relatively large economies and currency areas. The best performance is presented in VECM specifications with 3 and 4 lags and the short-term effect of the GPR index most likely has a positive sign, requiring several months to appear. This study also highlights the importance of country-specific indexes, with geopolitical risk related to Russia having a relatively large positive effect on bond yields and IRS rates in the analyzed period. This country-specific risk may have been an important driving factor behind the Granger causal effects presented this thesis. Thus, this paper contributes to the literature by suggesting that financial market participant should consider geopolitical risk as a factor in pricing financial products and managing interest rate risk.

This paper is organized as follows. Section 2 provides a description of the various GPR indexes used in this analysis. Section 3 sets out hypotheses based on influential economic theories regarding the response of bonds and IRS rates to geopolitical risk. Section 4 describes the data. Section 5 outlines the empirical analysis conducted for model selection. Section 6 provides a detailed description of the methodology used in the panel VECM analysis. Section 7 and 8 present results of the Granger causality tests and the corresponding impulse response functions. Finally, Section 9 provides a conclusion and answers the research question.

2. Geopolitical risk index

Caldara and Iacoviello (2022) propose a novel GPR index that is based on news coverage. The authors define geopolitical risk as 'the threat, realization, and escalation of adverse events associated with wars, terrorism, and any tensions among states and political actors that affect the peaceful course of international relations'. The index is constructed by counting the amount of news articles that cover risky events on a daily and monthly basis.

To identify adverse events, Caldara and Iacoviello (2022) use a dictionary of words related to geopolitical risk events. The general GPR index combines both acts and threats of adverse geopolitical events, while the authors also construct separate indexes for acts (GPA) and threats (GPT). The authors demonstrate that their indexes can capture the most significant periods of wars and tensions from 1900 and onwards, and that geopolitical risk is associated with reduced GDP growth. In addition, the authors assemble country-specific indexes that include geopolitical news related to a particular country. Caldara and Iacoviello (2022) suggest that these should reflect the different 'geographic imprint' of major geopolitical events. In this thesis, besides looking into the performance of the general GPR index, country-specific indexes are examined to identify regional characteristics of geopolitical risk.

Figure 1 graphically displays the global and regional GPR indexes for the period from 1990 to 2022. Figure 1 shows that the general GPR and U.S. index seem particularly related, as both present similar up- and downward movements across time. Furthermore, the Russia-specific index has an extreme spike in 2022, and only in this moment the Russian index overshoots each other index displayed Figure 1. This observation shows that the dataset of this thesis includes a recent major geopolitical event: the Russo-Ukrainian war. This feature is taken into account for interpretation of the performance of the GPR indexes. In Section 7, the global GPR index is applied to the full panel, while in Section 8, each index is utilized in sub-samples to investigate the geographical character of country-specific risk. A detailed description of the methodology for analyzing country-specific indexes is presented in paragraph 6.4.

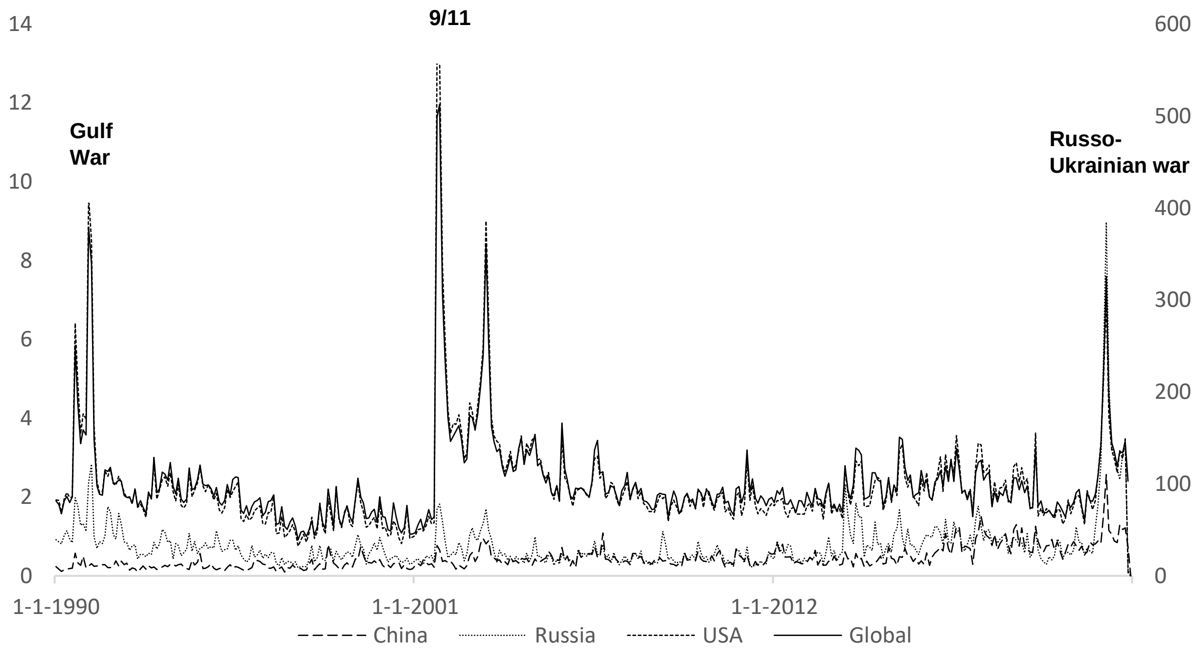

Figure 1 GPR indexes from 1990 to 2022.

3. Literature and hypotheses

This section outlines the hypotheses that complement the research question. In analyzing GPR indexes, this study draws upon the global monthly VAR model setting of Cadara et al. (2022). The base model in this thesis comprises of 7 variables, namely the industrial production index (IPI), the stock price index (MSCI), the consumer price index (CPI), the ER, the consumer confidence index (CCI) or VIX, the GPR index, and the bond yield or IRS rate. Further details on the data can be found in Section 4.

The underlying processes driving this model are rooted in macroeconomic theories that relate to the gross domestic product (GDP), the interest rate, inflation and the ER. Based on this literature, hypotheses can be constructed regarding the relationship between geopolitical risk and the remaining variables in the model.

3.1 Sovereign bonds

The first hypothesis is related to macro-financial theory that is characterized by its multidimensionality. Caldara et al. (2022) establish a positive link between the GPR index and inflation, both variables included in the model in this thesis. According to Caldara et al. (2022), geopolitical tension can lead to changes in fiscal and monetary policies that ultimately affect inflation. For instance, in a period of high geopolitical risk, countries may expand their fiscal policies by an increase in government spending on military activities, leading to a rise in aggregate demand (AD). The AD curve can be expressed as:

$$Y = C + I + G + NX, \tag{1}$$

Where Y represents GDP, C is consumption, I represents investment, G is government spending and NX is net exports.

G is expected to increase in the AD curve as a response to geopolitical turbulence. At the same time, geopolitical risk may disturb supply chains and international trade, leading to a relative decrease in aggregate supply, as also has been hypothesized by ING (2022). While geopolitical risk would induce both a demand and supply shift, Caldara et al. (2022) find that the aggregate demand effects offset the contrary shifts. This relative increase in aggregate demand would cause inflationary effects in the economy (Hicks, 1937). However, prices are sticky in the short-run, while interest rates can respond immediately to demand shifts. Given the monthly data examined in this thesis, the presumption is that we will observe an interest rate response to higher geopolitical risk.

Furthermore, Forbes and Warnock (2012) find that global risk is associated with abnormal capital flows. These authors identify types of capital flow episodes in international financial markets, and find that global uncertainty is expected to cause capital flights to safe economies, causing a relative appreciation of the dollar and higher import prices in dollar terms. Most economies in the dataset of this thesis will consequentially be expected to experience rising inflation in periods of increased geopolitical risk.

Additionally, most central banks commit to inflation targeting policies. According to the Taylor rule for monetary policy, central banks are expected to contract monetarily in response to higher inflation, by increasing interest rates (Taylor, 1993). Most central banks are found to alter policies every 1 or 2 months (Bank of England, 2012), which allows the interest rate to respond in the monthly setting of this thesis. On top of that, interest rates do not need to rise solely based on the lagged CPI values in the model setting of this thesis, as central banks are expected to be forward looking (Clarida, Gali & Gertler, 1998). Hence, central banks would already set interest rates in response to expected inflationary effects of geopolitical turbulence in the present. In summary, interest rates are expected to rise in the short-run in response to a shock in geopolitical risk. The first hypothesis is therefore formulated as follows:

Hypothesis 1: Global geopolitical risk is positively related to bond yields.

Hypothesis 1 will be accepted if significant Granger causality is observed with 95% confidence for at least 5 out of 9 bond maturities in the full sample results of paragraph 7.1, as well as in the separate samples of advanced and non-advanced economies. These results need to correspond to strictly positive impulse responses with 95% confidence in each case.

3.2 Interest rate swaps

This study aims to investigate not only bonds, but also plain vanilla IRS rates, of which the floating leg is determined by the interbank interest rate. Following Duffie and Singleton (1997), the pricing of a plain vanilla IRS can be expressed by:

$$C_t^m = \frac{1 - B_t^{\tau m}}{\sum_{j=1}^{2\tau m} B_t^{0.5j}}, \tag{2}$$

where C denotes the fixed coupon rate, τm represents the maturity of the mth swap, $1 - B_t$ is the present value of the floating rate payments and j is a summation over the range of the coupon payments.

Hypothesis 1 postulates that in response to geopolitical tensions, we expect raised interest rates within several months. This response is expected to affect the interbank rates as well, such as the London Interbank Offered Rate (LIBOR), that are considered for pricing IRS rates. Equation (2) demonstrates a positive correlation between IRS rates and interbank interest rate levels, leading to the second hypothesis:

Hypothesis 2: Global geopolitical risk is positively related to IRS rates.

To validate the second hypotheses, Granger causality must be observed in more than half of the modelled maturities in both the full sample results of paragraph 7.1, as well as the separate samples of advanced and non-advanced economies. These results need to correspond to strictly positive impulse responses with 95% confidence in each case.

3.3 Country-specific risk

In their 2022 study, Caldara and Iacoviello's (2022) general GPR index captures the most significant periods of wars and tensions. In the sample period of this thesis, the global GPR index spikes during major geopolitical conflicts as well, emphasizing the role of geopolitical actors and wars with each geographical, or regional features. These features imply that geographically conflict-exposed regions could experience more abnormal capital flows (Forbes and Warnock, 2012), stronger aggregate demand and supply shifts (Caldara et al, 2022), and corresponding severe monetary contractions (Clarida, Gali & Gertler, 1998).

The third hypothesis addresses this geographical variation and builds on Caldara and Iacoviello's (2022) suggestion that country-specific risk indexes reflect a geographical imprint. The considerable increase in the Russian GPR index during the Russo-Ukrainian war, as shown in Figure 1, underscores the ability of country-specific indexes to highlight conflicts involving particular nations. The expectation is that country-specific risk indexes will emphasize the regional risks related to a particular geopolitical actor, and that indexes of regional geopolitical actors will have a more pronounced relationship with bond yields in their own region, relative to the general GPR index. Hence, the third hypothesis is as follows:

Hypothesis 3: In conflict-exposed regions, bond yields are more related to country-specific than to global geopolitical risk.

This hypothesis will be accepted if the country-specific indexes for the USA, Russia and China show more significant cases of Granger causality than the global index in their respective regional groups. As a result, the Russian index should perform better in Eastern Europe, the U.S. index in Western subjects, and the Chinese index in Asia and the Pacific.

3.4 Long-run equilibrium

In paragraph 3.1, it is hypothesized that macro-economic variables will move conforming to theoretical concepts. Such theories rely on the existence of a certain economic equilibrium for variables included in the model of this study, being interest rates, ER, GDP and inflation. GDP is in this study proxied by the IPI, while the included MSCI variables are driven by GDP growth in the long term as well. According to the literature, a long-run equilibrium for these variables should be accounted for by assuming *cointegration* between macro-economic variables in the model (Nelson & Plosser, 1982). In this thesis, we adopt this assumption and hypothesize the existence of a long-run equilibrium between the ER, IPI, CPI, interest rate and MSCI. As a result, we examine the GPR index in a VECM, a model framework that relies on the same long-run assumption. Section 5 provides an additional empirical analysis of this long-run relationship and Section 6 describes model assumptions in detail.

4. Data

4.1 Data description

The analysis of bond yields is composed of unbalanced panel data that ranges from January 1st, 1990, to December 1st, 2022, and consists of 45 subjects. Appendix A provides a list of countries included in this sample. The base model comprises 7 variables. Government bond yields are measured by monthly averages of day-closing bid prices of the Refinitiv Eikon government bond yield benchmark index, across 9 maturities ranging from 1 month up to 30 years. Inflation is measured by the monthly CPI of each country. MSCI country-level stock indexes, collected at the end of the month, represent the stock price of each country. The nominal ER is collected at the end of the month and is expressed in price notation relative to the U.S. Dollar (USD), while for the U.S. the USD is measured relative to the euro. In this notation, an increase in each ER equates to a depreciation. GDP is proxied by the national IPI and consumer confidence is reflected by the national CCI. Both are determined at a monthly frequency.

The analysis of IRS rates comprises data from 23 currency areas, consisting of 22 equal subjects from the first analysis and the Euro Area. Appendix A denotes the subjects included. This model also includes 7 variables, with the IRS as the target variable in place of bonds. IRS rates are reflected by monthly averages of day-closing bid prices of plain vanilla IRS rates. In each swap the floating leg is the 3 or 6-month interbank rate and the maturities range from 6 months to 30 years. Most subjects include only IRS rates with a 3-month floating leg (3FL) or a 6-month floating leg (6FL). Paragraph 4.2 describes the sample characteristics in detail. For the Euro area, the stock price is reflected by the MSCI Economic and Monetary Union index collected at the end of the month, while the OECD aggregate Eurozone indexes represents the monthly IPI and CCI. The remaining currency-specific models contain non-target variables that equal the variables included in the first analysis.

Finally, In each subject, the global, Russian, Chinese and U.S. GPR index are equal and retrieved from matteoiacoviello.com. Besides, robustness tests in paragraph 7.2 and regional samples in 8.2 consider the VIX instead of the CCI as a measure of market expectations. The daily VIX is retrieved from Refinitiv Eikon and is included as a monthly average that is equal in each subject.

4.2 Sample characteristics

This study explores the relationship between the GPR index and bond yields or IRS rates across various maturities, each with distinct sample characteristics. Sample sizes in the unbalanced dataset are dependent on availability of the target variable and non-target variables included in the model. As most subjects often provide IRS rates based on either a 3 or 6-month floating leg, this could cause a selection effect. Furthermore, sample sizes for certain IRS maturities are relatively small. To correct for these two limitations, the analysis of IRS rates includes a larger number of maturities. Additionally, maturities with larger sample sizes tend to include more non-developed economies, as these offer relatively fewer bonds and IRS types. Section 8 therefore concentrates on disentangling responses by economy type, while Section 7 presents results that cover the full sample with a focus on external validity and sample size.

Table 1 *Unit root tests for non-target variables in levels.*

	No constant				Constant			
		LLC	ADFF	PPF	LLC	IPS	ADFF	PPF
GPR	Stat	-17.991	453.978	487.522	-43.192	-42.776	1961.89	2822.52
	P	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
IPI	Stat	2.3143	28.497	29.971	-0.689	-1.346	171.13	536.043
	P	0.99	1	1	0.245	0.089*	0.000***	0.000***
MSCI	Stat	0.389	64.246	64.419	0.941	-0.403	119.035	125.902
	P	0.652	0.999	0.999	0.827	0.344	0.149	0.071
ER	Stat	1.07	32.466	31.631	7.386	1.62	172.659	174.714
	P	0.858	1	1	1	0.947	0.000***	0.000***
CCI	Stat	-1.048	40.583	44.583	-1.092	-9.444	249.949	156.646
	P	0.147	0.999	0.995	0.137	0.000***	0.000***	0.000***
CPI	Stat	20.19	7.983	0.789	13.535	20.359	33.197	63.605
	P	1	1	1	1	1	1	0.998
VIX	Stat	-10.402	204.058	124.59	-10.793	-26.313	947.002	1074.01
	P	0.000***	0.000***	0.0825	0.000***	0.000***	0.000***	0.000***

Note: ADFF denotes the Fisher-type ADF test, PPF the Phillips-Perron – Fisher test, LLC the Levin, Lin and Chu test and IPS the Im, Pesaran and Shin test. The LLC statistic assumes common unit root processes, while the IPS, ADF and PPF assume individual unit root processes. ** and *** denote tests that reject the null with 95 and 99% confidence.

Furthermore, the CCI, which would capture effects of market expectations and uncertainty other than geopolitical risk, is missing in several subjects, particularly less developed countries. Subjects with available CCI data are denoted in Appendix A. To address this problem, robustness tests in Section 7.2.2 replace the CCI by the VIX for expanded samples including more diverse economies. In Section 8.2, the regional analysis is performed with the VIX for sample size purposes as well.

5. Empirical analysis

The VAR model was introduced by Sims (1980), earning widespread economic application by allowing a model to consist of only endogenous variables. The potential for cointegration among first order integrated variables, however, imposes restrictions on the VAR (Pesaran & Smith, 1998). The VECM expands on the VAR model by the inclusion of error correction properties, and is suitable with cointegrating variables (Engle & Granger, 1987).

Estimation of a VAR or specialized VAR model entails several econometric steps. This chapter outlines the steps for model selection to examine the relationship between de GPR index and bond yield or IRS rate. Paragraphs 5.1 and 5.2 provide unit root and lag selection test results, while paragraph 5.3 reports cointegration test results investigating the long-run equilibrium among model variables hypothesized in Section 3.

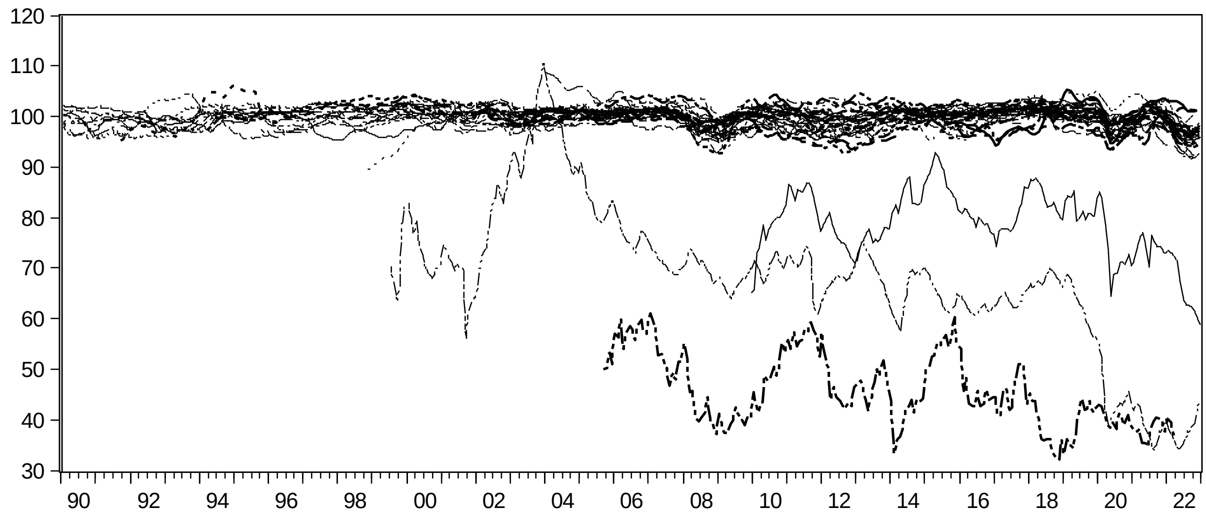

Figure 2 Consumer confidence indexes from 1990 to 2022.

5.1 Unit root

The first step in VAR and VEC model selection is to ensure that the variables are integrated to at most the first order. If the variables are non-stationary in levels, they must be included in first differences in the case of selecting the VAR. In this paragraph, each variable in the panel dataset is tested for unit root under varying assumptions to improve robustness of the analysis. Panel unit root tests are conducted using Fisher-type (Choi, 2001) Augmented Dickey Fuller (Dickey & Fuller, 1979) and Phillips-Perron (Phillips & Perron, 1988) tests, as well as Levin, Lin and Chu (2002) and Im, Pesaran, and Shin (2003) tests. Results of panel unit root tests in levels for the non-target variables are presented in Table 1. The null hypothesis of unit root can not be significantly rejected in all cases. The GPR and VIX have p-values that reject the null of panel unit root in almost every case with 99% confidence. Table 1 shows that for the CPI and MSCI, each p-value is larger than 0.05, and the null of unit root can not be rejected. Hence, the GPR and VIX can be considered stationary in levels, while the CPI and MSCI are considered non-stationary. This finding is not contradictory to the hypothesis in Section 5 that the variables CPI and MSCI would be cointegrating.

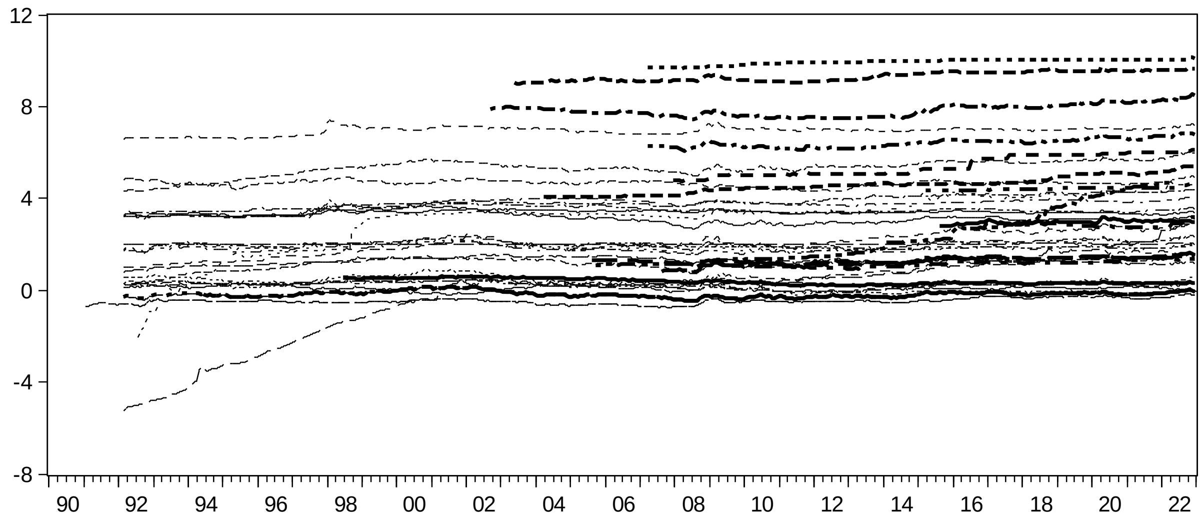

Figure 3 Exchange rates in log terms from 1990 to 2022.

The results for ER, IPI and CCI are less conclusive with both significant and non-significant evidence for stationarity with 95% confidence, thus requiring graphical substantiation. Figure 2 shows that CCI levels are roughly stable around an intercept, which is typically 100. Although the CCI shows a slight downward movement in 2 subjects, this pattern is too inconsistent to assume non-stationarity in the CCI. The CCI is as a result considered stationary, which is in line with the nature of the CCI as a confidence measure that typically moves around a certain base confidence level. The pattern in Figure 3 shows that ER’s generally follow an upward, depreciating trend relative to the USD. Despite the results in Table 1, the ER can therefore not be considered stationary. Lastly, Figure 4 displays that although Table 1 shows suggestive evidence for stationarity, IPI levels are generally increasing over time. Non-stationarity therefore needs consideration in the models for this variable.

Together, the graphical analysis does not oppose the hypothesis that IPI and ER are non-stationary variables moving according to a long-run equilibrium. The conclusion is that non-stationarity in levels consists among the variables and should be assumed in model specifications. A VAR can consequentially not be estimated with variables in level form.

The next step is examination of panel unit root among the variables in differenced form. Subsequent panel unit root tests in first differences demonstrate stationarity in first differences with a high degree of confidence in each case in both target and non-target variables (99.9%). Unit root tests for non-target variables in first differences are presented in Appendix B. These findings allow for performing cointegration tests in the subsequent phase of model selection.

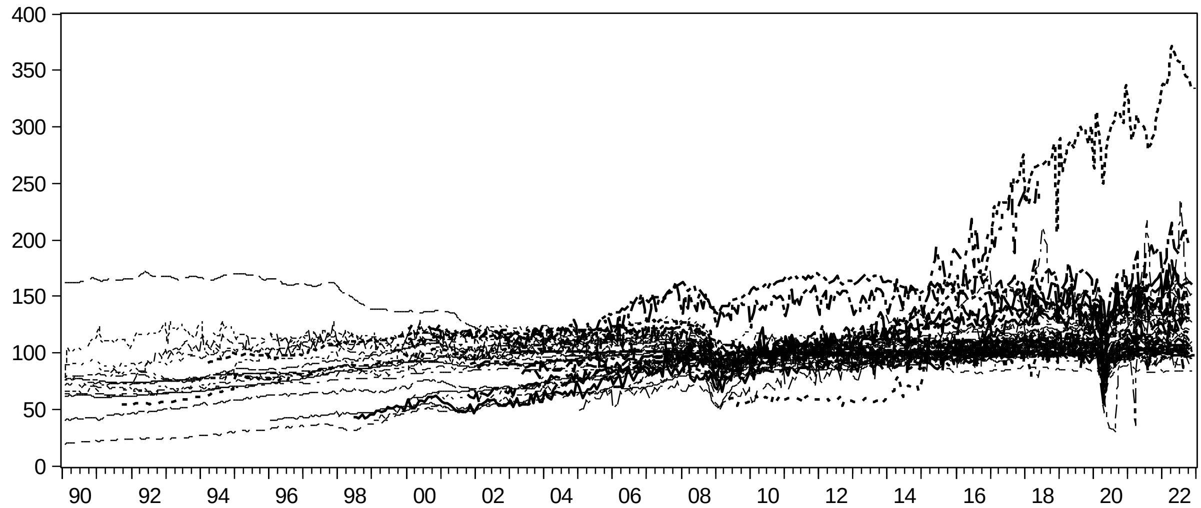

Figure 4 Industrial production index from 1990 to 2022.

Finally, the unit root analysis pertains to whether the bond yield and IRS target variables are non-stationary in levels and necessitate inclusion in the cointegration tests. Appendix C shows that bond yields are stationary in nearly every panel unit root tests with confidences surpassing 99%. In contrast, Appendix D presents less conclusive results for 3FL IRS rates, with numerous tests still displaying panel unit root for the 6FL IRS rates. Despite the panel unit root test results, Figure 5 graphically depicts a negative trend in bond yields within the sample period. Appendix J exhibits analogous non-stationary graphical patterns for the IRS rates. Considering both IRS and bond yields as stationary variables is consequently constituted as a strong assumption that diverges from both the graphical pattern, and the theories and findings presented in Section 3. Thus, non-stationarity is regarded as a more reliable assumption in this thesis, and the target variables are hence considered accordingly. Cointegration tests, with and without target variables included, are presented in paragraph 5.3.

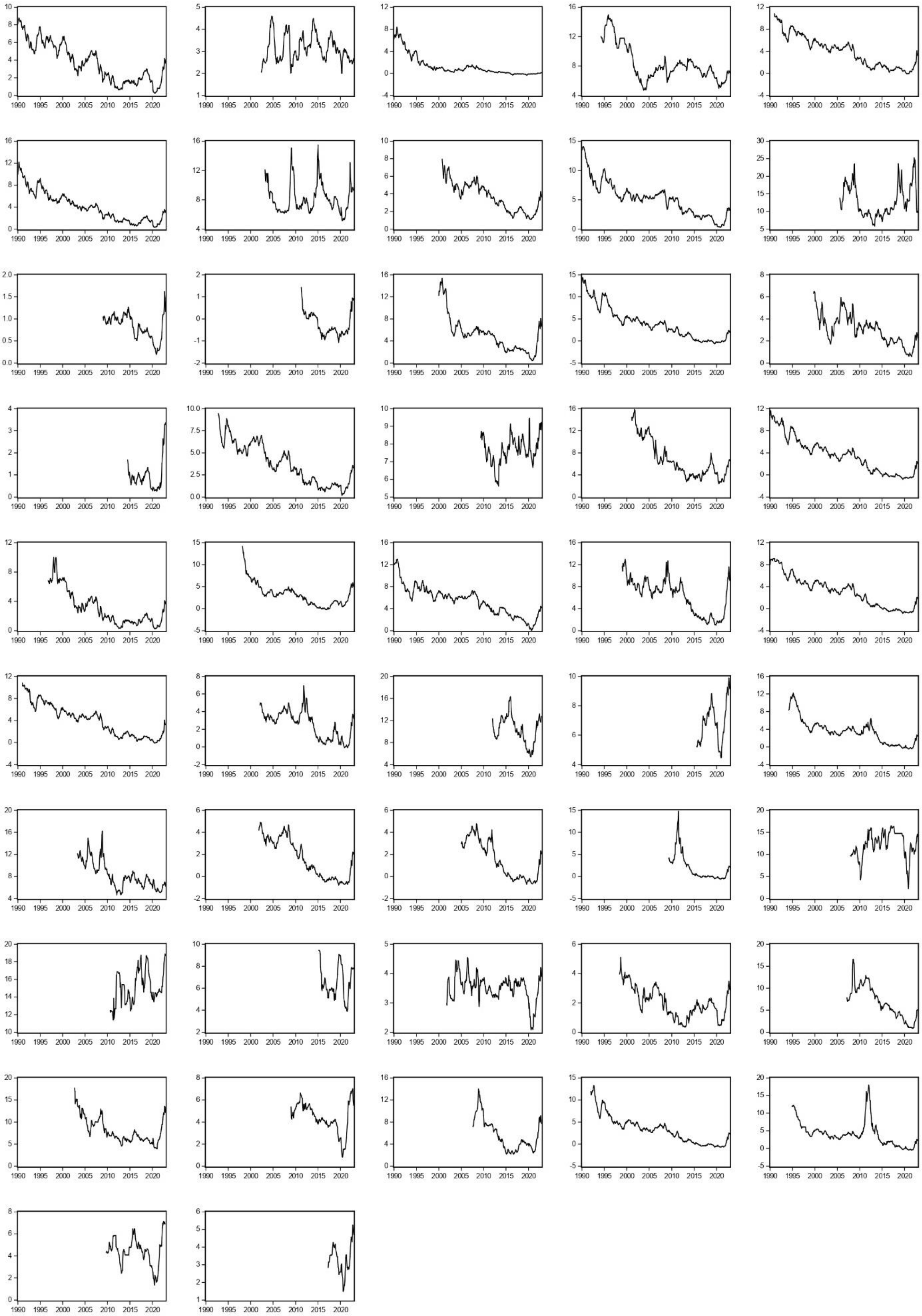

Figure 5 Bond yields with 5-year maturity from 1990 to 2022.

5.2 Lag selection

When selecting an appropriate VAR or VECM model, the next step is to determine the lag length. This can be achieved by interpreting the Akaike Information Criterion (AIC) (Akaike, 1974) and the Bayesian Information Criterion (BIC) (Schwarz, 1978). These criteria have different characteristics that require careful consideration of the research question and data. This study places particular emphasis on Granger causality tests, which are highly sensitive to the lag length in a VAR-type model (Zapata & Rambaldi, 1997). In this regard, the AIC is prone to overestimating the lag length, while the BIC tends to underestimate it (Bruns & Stern, 2019). Given the focus on Granger causality tests, the BIC is applied in this study to prevent overfitting in the model and producing false positive findings. The BIC is defined as:

$$BIC = kln(n) - 2\ln(L), \tag{3}$$

where k is the amount of parameters in the model, n the number of observations and L the model likelihood function.

The tested models in Table 2 include the level form of all 7 variables among which the CCI or VIX. 7 out of 9 tests for the models with the CCI provide a maximum lag length of 4, while for the VIX 5 out of 9 tests find an optimum of 3 or 4 lags. Table 3 presents BIC criteria for IRS rates, that are optimal in all cases between 2 and 4 lags. The results reveal that the majority of models have the lowest BIC with lag lengths ranging from 2 to 4. Although some tests for bond yields suggest higher lag lengths, models with more than 4 lags are not considered to prevent overfitting. Nonetheless, to ensure robustness, models with 2, 3 and 4 lags will be estimated, corresponding to 3 model types for each target variable.

Table 2 *Lag selection tests results for bond yields.*

	CCI				VIX			
	lag	obs	LogL	BIC	lag	obs	LogL	BIC
1m	4	2521	-20162.9	16.627	4	3340	-28754	17.7111
3m	4	3406	-26777.9	16.209	4	5007	-44808	18.2434
6m	4	2997	-23535.6	16.248	4	4425	-39735	18.3443
1y	4	3592	-28350.4	16.248	5	5334	-50015	19.1587
2y	4	4793	-36250.3	15.485	8	6178	-52359	17.5138
5y	4	5164	-38715.6	15.331	8	6853	-57446	17.2795
10y	8	5231	-38336.5	15.311	8	7075	-60153	17.5043
20y	3	2839	-22680.9	16.41	3	3554	-30176	17.3355
30y	4	3053	-18363.3	12.563	3	3652	-29449	16.4736

Note: The 'lag' column denotes the optimal lag in tests including a maximum amount of 12 lags.

5.3 Cointegration

The third step in the analysis involves assessing cointegration among the non-stationary variables in the model. Cointegration tests are utilized to determine whether non-stationary variables have a long-run relationship, which arises from a latent factor driving the cointegrating variables together. This latent factor could induce a combination of first-order integrated variables to form a stationary linear combination. If such a relationship is present, a VECM is more appropriate than a VAR model. Theories discussed in Section 3 suggests that a single long-run relationship could exist between the variables in the model.

Table 3 *Lag selection tests results for IRS rates.*

	3FL				6FL			
	Lag	obs	LogL	BIC	Lag	obs	LogL	BIC
1y	4	1676	-32711.1	40.204	2	1121	-6278.97	11.860
2y	4	1076	-9644.85	19.244	2	1647	-8475.2	10.764
3y	4	1076	-9538.28	19.046	2	1647	-8506.68	10.802
4y	4	1076	-9484.51	18.946	2	1647	-8525.42	10.825
5y	4	1076	-9419.44	18.825	2	1647	-8535.84	10.838
6y	3	672	-4236.61	14.101	3	1419	-4440.16	7.046
7y	3	672	-4224.96	14.066	2	1647	-8515.62	10.813
8y	3	672	-4220.65	14.053	3	1419	-4410.7	7.004
9y	2	876	-4507.06	11.102	3	1419	-4391.14	6.977
10y	2	876	-4507.06	11.102	2	1647	-8487.33	10.779
12y	3	552	-1898.04	8.638	3	334	-388.505	5.006
15y	2	750	-5806.95	16.412	2	1265	-5530.42	9.337
20y	3	700	-4446.82	14.146	2	1186	-5237.35	9.459
25y	3	333	-1084.29	9.198	2	810	-2847.33	7.899
30y	3	421	-1408.79	8.903	2	763	-2530.88	7.547

Note: The ‘lag’ column demotes the optimal lag amount in tests including 1 up to 12 lags.

Panel cointegration test have been conducted for all 5 non-stationary variables using various test types, including those designed by Pedroni (1999), Kao (1999) and Westerlund (2005). Test results among the non-target variables are presented in Table 4. Except for 3 test results, significant p-values are found indicating panel cointegration between the ER, MSCI and IPI under all assumptions and among various test types. This evidence shows that at least these three variables within the model are cointegrating, thus requiring incorporation of cointegration in the model through a VECM.

Table 4 C*ointegration tests for CPI, ER, MSCI and IPI.*

					excluding CPI	
test	assumption	type	stat	p	stat	p
Pedroni		Mod. PP	-21.082	0.000***	-25.842	0.000***
		PP	-0.287	0.387	-4.417	0.000***
		ADF	-0.533	0.297	-3.850	0.000***
Pedroni	No constant	Mod. PP	-19.797	0.000***	-20.973	0.000***
		PP	0.075	0.470	-6.241	0.000***
		ADF	-0.34	0.367	-5.089	0.000***
Pedroni	demean	Mod. PP	-2.422	0.008***	-20.119	0.000***
		PP	14.961	0.000***	-1.714	0.043**
		ADF	18.178	0.000***	-1.277	0.101
Pedroni	trend	Mod. PP	-29.287	0.000***	-30.171	0.000***
		PP	-5.776	0.000***	-5.169	0.000***
		ADF	-7.944	0.000***	-4.010	0.000***
Kao		Mod. DF	6.027	0.000***	5.546	0.000***
		DF	5.691	0.000***	7.639	0.000***
		ADF	6.352	0.000***	7.280	0.000***
		Unadj. mod. DF	7.710	0.000***	5.741	0.000***
		Unadj. DF	10.901	0.000***	8.071	0.000***
Kao	demean	mod DF	10.120	0.000***	-0.584	0.278
		DF	10.563	0.000***	0.921	0.178
		ADF	15.886	0.000***	5.055	0.000***
		Unadj. Mod. DF	10.067	0.000***	-10.133	0.000***
		Unadj DF	13.956	0.000***	-4.147	0.000***
Westerlund	Some panels	variance ratio	-1.063	0.144	-5.208	0.000***
Westerlund	Trend	variance ratio	-5.513	0.000***	-4.436	0.000***
Westerlund	All panels	variance ratio	-0.919	0.179	-2.231	0.013**
Westerlund	Demean	variance ratio	-2.744	0.003***	-3.596	0.000***

Note: The table displays test statistics of panel cointegration tests. Tests have been performed with automatic lag selection. Tests excluding CPI include only the ER, MSCI and IPI variables. ** and *** denote tests that reject the null with 95 and 99% confidence. Tests with predetermined lags provide well comparable results. PP denotes Phillips-Perron tests, (A)DF denotes (Augmented) Dickey-Fuller tests.

Test results for cointegration among all 5 non-stationary variables, including each target variable, are presented in Appendices E and F. A majority of the tested combinations presents 95% confidence of cointegration under each assumption, and all target variables present significant p-values lower than 5% in roughly half of the cases. Although these results are less conclusive, the p-values lend support for assuming the presence of a cointegration relationship among all 5 non-stationary variables in each model. This finding aligns with the macroeconomic theories discussed in Section 3, and as a result the VECM model is estimated under the assumption that all 5 non-stationary variables in levels are cointegrating.

Given the diversity in test results across combinations of target variables and test assumptions in Appendices E and F, a default VECM model with a single cointegrating equation and a constant is assumed for each target variable. Although the focus in this thesis is not on identifying the true long-run relationship between the variables, tests under deviating assumptions regarding the VECM model are conducted in Section 7, to examine the impact of this long-run assumption for Granger causality test results.

6. Methodology

The theories discussed in Section 3 and empirical analysis presented in Section 5 substantiate the assumptions that underlie the selection of a VECM. A detailed description of the model and its assumptions is provided in paragraph 6.1. In the subsequent paragraphs, we illustrate the application of this model for Granger causality tests and construction of IRF's, which are ultimately used to analyze the relationship between geopolitical risk and bond yields or IRS rates.

6.1 Panel VECM

A panel VECM is an expanded version of the panel VAR model that incorporates a correction for the long-run relationship, or cointegration, among the variables by including an error correction term. The VECM is useful in explaining how the variables respond to shocks in the short-run and eventually move towards their long-term equilibrium. Specifically, a panel VECM of only endogenous variables can be stated as follows:

$$\Delta Y_{ijt} = \beta_{0ij} + \sum_{l=1}^{k} \beta_{ijl} \, \Delta Y_{ijt-l} + \lambda_{ij} ECT_{jt-1} + u_{ijt}, \qquad (4)$$

where ΔY_{ijt} represents the change in the ith endogenous variable for the jth subject at time t, β_{0ijt} is the constant term, $\sum_{l=1}^{k} \beta_{ijl}$ represents the lagged coefficients up to the kth lag, λ_{ij} represents the long-run equilibrium relationship between the ith endogenous variable for the jth subject and the error correction term ECT_{t-1}, and u_{ijt} represents the error term or residual.

ECT_{t-1} is the lagged residual of the cointegrating equation:

$$R_{jt} = \beta_{0j} + \beta_{1j} IPI_{jt} + \beta_{2j} lnMSCI_{jt} + \beta_{3j} CPI_{jt} + \beta_{4j} lnER_{jt} + \beta_{5j} EXP_{jt} + \beta_{6j} GPR_{jt} + u_{jt}, \qquad (5)$$

where R_{tj} is the bond yield or IRS rate for subject j, EXP_{tj} denotes market expectations measured by the CCI or VIX, and β are the model parameters.

As indicated in paragraph 5.1, not all variables in the model are non-stationary in levels, and hence they are not cointegrating with the other variables. The literature proposes different views on dealing with combinations of $i(0)$ and $i(1)$ variables in a VECM. Several researchers approach short-run and long-run dynamics solely through the cointegration properties of the model variables, while others base their model specification on theoretical views (Levtchenkova, Pagan & Robertson, 1998). In this thesis the VIX, CCI and GPR are assumed to capture short-run shocks to the long-run macroeconomic system of variables, and excluded from the long-run equilibrium assuming $\beta_5 = \beta_6 = 0$ in equation (5). Moreover, we assume no long-run adjustment of the VIX, CCI and GPR index, by setting $\lambda_i = 0$ for these variables in equation (4).

6.2 Granger causality

In the selected VECM framework, the relationship between the GPR index and the target variables is investigated through the application of Granger causality tests (Granger, 1969). Granger causality refers to the situation where a time-series variable can be employed for predicting a second time-series variable. In this study, the impulse variable is the change in the GPR index, either country-specific or global, while the dependent variable is the change in IRS rate or bond yield. The Chi-square statistic is utilized to conduct the Granger causality tests:

$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}, \tag{6}$$

where χ_c^2 is the test statistic with c degrees of freedom, O_i is the observed value, and E_i the expected value of the variable.

The null hypothesis of Granger causality tests is no Granger causal effect of the GPR index, while the alternative hypothesis is that the GPR index is relevant for predicting the target variable. The GPR index is considered to be Granger causing the target variable if the test statistics correspond to at least 95% confidence. Test statistics are reported in Section 7 and 8.

6.3 Impulse response function

While the Granger causality tests allow for finding a predictive relationship between the GPR index and the target variables, coefficients in VEC models are hard to interpret. Impulse response functions (IRF) provide more detailed graphical information regarding the relationship between the two variables. The IRF shows what the strength of the response is to an impulse by a shock in the GPR index, and whether this connection is positive or negative. In this thesis, only IRF's are interpreted that correspond to models where a Granger causal effect of the GPR index is found with at least 95% confidence. Reported IRF's are non-factorized and impulses are in each case a one standard deviation (SD) innovation of the GPR index. Each presented IRF reports 95% confidence intervals calculated using standard percentile bootstraps with 999 repetitions.

Table 5 *Granger causality tests for bond yields.*

	2 lags			3 lags			4 lags		
	Chi-sq	p	obs	Chi-sq	p	obs	Chi-sq	p	obs
1M	2.333	0.312	3310	2.988	0.394	3219	3.765	0.439	3128
3M	7.933	0.019**	4443	10.154	0.017**	4323	10.579	0.032**	4203
6M	4.681	0.096	3930	5.602	0.133	3822	7.631	0.106	3714
1Y	1.91	0.385	4818	2.118	0.548	4671	1.889	0.756	4525
2Y	4.057	0.132	6346	8.53	0.036**	6164	9.477	0.05	5983
5Y	3.858	0.145	6800	9.061	0.029**	6608	10.927	0.027**	6417
10Y	4.469	0.107	6877	8.973	0.03**	6684	11.608	0.021**	6492
20Y	3.748	0.154	3864	19.306	0.000***	3741	27.867	0.000***	3620
30Y	8.946	0.011**	4100	25.56	0.000***	3974	31.64	0.000***	3849

Note: The table lists p-values of Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on bond yield as dependent variable are in each case equivalent to over 99,9% confidence.

6.4 Country-specific risk

Matteo and Iacoviello (2022) posit that country-specific risk indexes reflect the geographic imprint of threats and events. Building on this notion, this study hypothesizes that within a region, country-specific geopolitical risks regarding the regional major geopolitical actor have a more pronounced relationship with bond yields than the general index, reflecting the region's higher exposure to conflict risks from this country. To test this hypothesis, in paragraph 8.2 the sample is divided into five regional groups of Member States from the United Nations (United Nations, 2017): Western States, Asia-Pacific States, African States, Eastern European States and Latin American and Caribbean States. These groups have both geographical and geopolitical bases (Thakur, 1999) and are thus suitable for testing hypothesis 3. Granger causality tests and IRF's are constructed in each sample to evaluate whether regions exhibit amplified responses to the respective country-specific GPR indexes. Appendix A links each subject in the sample to the corresponding regional group.

To investigate regional features of geopolitical risk indexes, the country-specific GPR indexes of three major geopolitical actors, namely Russia, China and the U.S., are incorporated into the regional models and compared to the general GPR index. This methodology therefore exploits regional differences across risk measures within a regional sample, rather than differences in the impulse of a single risk measure across regions. To ensure sufficient sample sizes in each sub-sample, this regional analysis is only conducted for bonds, and the group of African states is excluded from the analysis. Furthermore, the VIX is utilized in place of the CCI as a market expectation measure.

Table 6 *Granger causality tests for 3FL IRS rates.*

	2lags			3lags			4lags		
	Chi-sq	p	obs	Chi-sq	p	obs	Chi-sq	p	obs
1y	3.403	0.182	2298	3.754	0.289	2224	3.906	0.419	2151
2y	3.543	0.17	1514	6.476	0.091	1461	8.865	0.065	1409
3y	2.996	0.224	1514	5.472	0.14	1461	8.408	0.078	1409
4y	2.918	0.232	1514	6.353	0.096	1461	9.782	0.044**	1409
5y	3.026	0.22	1514	7.098	0.069	1461	11.888	0.018**	1409
6y	2.81	0.245	882	14.119	0.003***	857	24.389	0.000***	832
8y	2.647	0.266	882	15.097	0.002***	857	24.498	0.000***	832
9y	2.846	0.241	882	15.613	0.001***	857	24.249	0.000***	832
10y	1.113	0.573	1244	19.311	0.000***	1199	28.439	0.000***	1155
12y	0.31	0.856	721	10.136	0.017**	702	11.483	0.022**	683
15y	4.623	0.099	974	22.137	0.000***	948	29.105	0.000***	922
20y	4.056	0.132	915	9.083	0.028**	890	13.51	0.009***	865
25y	1.496	0.473	441	1.668	0.644	428	1.765	0.779	415
30y	1.74	0.419	556	4.572	0.206	540	6.155	0.188	524

Note: The table lists p-values of Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on IRS rate as the dependent variable are in each case equivalent to over 99,9% confidence.

7. Full sample results

In this section we examine the entire sample for a link between geopolitical risk and bond yields and IRS rates in the manner described in Section 6. In paragraph 7.1, Granger causality tests are performed to investigate this link in the main model. In paragraph 7.2, additional Granger causality test results are reported in deviating models for robustness purposes. These tests consider models that include the VIX in stead of the CCI variable, as well as models with alternative assumptions regarding the cointegration equation. Paragraph 7.3 analyzes the sign and magnitude of the presented significant Granger causal effects by examining IRF's.

7.1 Granger causality tests

The Granger causality test results for bonds are presented in Table 5, while tests for IRS rates are in Table 6 and 7. Table 5 indicates that the general GPR index Granger causes bond yields with at least 95% confidence in 13 out of 27 specifications. This significant result is found for bond yields with a 3-month maturity, and maturities of 2 up to 30 years. Moreover, the significance of the results in each case is consistent for both the models with 3 and 4 lags, while the specifications with 2 lags generally provide less evidence for Granger causality.

Table 7 *Granger causality tests for 6FL IRS rates.*

	2lags			3lags			4lags		
	Chi-sq	p	obs	Chi-sq	P	obs	Chi-sq	p	obs
1y	9.992	0.007***	1409	7.621	0.055	1376	10.344	0.035**	1343
2y	6.515	0.039**	2070	13.336	0.004***	2022	14.81	0.005***	1974
3y	8.667	0.013**	2070	16.66	0.001***	2022	21.24	0.000***	1974
4y	7.78	0.021**	2070	15.403	0.002***	2022	22.773	0.000***	1974
5y	7.454	0.024**	2070	14.165	0.003***	2022	23.266	0.000***	1974
6y	8.093	0.018**	1789	18.927	0.000***	1747	24.873	0.000***	1705
7y	5.183	0.075	2070	11.241	0.011**	2022	20.335	0.000***	1974
8y	6.759	0.034**	1789	17.125	0.001***	1747	22.746	0.000***	1705
9y	6.656	0.036**	1789	17.46	0.001***	1747	23.231	0.000***	1705
10y	4.277	0.118	2070	9.28	0.026**	2022	19.115	0.001***	1974
12y	10.462	0.005***	1615	34.764	0.000***	1573	36.623	0.000***	1532
15y	9.453	0.009**	1618	39.624	0.000***	1576	36.428	0.000***	1534
20y	6.387	0.041**	1505	37.23	0.000***	1468	34.741	0.000***	1431
25y	2.854	0.24	1012	23.818	0.000***	988	24.707	0.000***	964
30y	5.423	0.066	956	37.011	0.000***	933	35.038	0.000***	910

Note: The table lists p-values of Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on IRS rate as the dependent variable are in each case equivalent to over 99,9% confidence.

Table 6 illustrates that, in the base model, the GPR index Granger causes 3FL IRS rates in 16 out of 42 specifications and maturities ranging from 6 up to 20 years. The confidence level is in most cases at least 99% and consistent in models with 3 and 4 lags, while no significant results are found for models including 2 lags. Finally, Table 7 reports that in 6FL IRS rates Granger causality is found in 40 out of 45 models and for all maturities, with confidence levels generally over 99%. Furthermore, significant p-values are consistent for models with 3 and 4 lags, while p-values with 95% confidence are still found in more than half of the models with 2 lags.

7.2 Robustness tests

In paragraph 6.1, the findings show significant results of Granger causality of the GPR index for IRS rates and bond yields. However, these results may be subject to limitations that require further investigation. Specifically, the VECM is based on assumptions in the cointegrating equation that reflect the long-run relationship between the macro-economic variables in the model. To test the stability of the results without imposing restrictions on the cointegrating equation, additional tests are conducted in paragraph 7.2.1. Moreover, the inclusion of the CCI variable limits the amount of subjects in the sample. To address this problem, tests have been conducted in paragraph 7.2.2 where the VIX replaces the CCI variable.

Table 8 *Granger causality tests for bond yields with no restrictions.*

	2 lags			3 lags			4 lags		
	Chi-sq	p	obs	Chi-sq	p	obs	Chi-sq	p	obs
1M	1.183	0.554	3311	1.798	0.615	3220	2.2144	0.696	3129
3M	4.400	0.111	4444	6.214	0.102	4324	7.776	0.100	4204
6M	3.656	0.161	3931	4.571	0.206	3823	6.644	0.156	3715
1Y	1.971	0.373	4819	2.453	0.484	4672	3.673	0.452	4526
2Y	4.498	0.106	6347	9.023	0.029**	6165	10.390	0.034**	5984
5Y	4.386	0.112	6801	7.612	0.055	6609	10.059	0.040**	6418
10Y	5.354	0.069	6878	9.232	0.026**	6685	12.884	0.012**	6493
20Y	4.763	0.092	3865	19.052	0.000***	3742	26.996	0.000***	3621
30Y	18.218	0.000***	4100	27.381	0.000***	3974	34.256	0.000***	3849

Note: The table lists p-values of Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on bond yield as the dependent variable are in each case equivalent to over 99,9% confidence.

7.2.1. Restrictions cointegrating equation

Paragraph 6.1 describes that the CCI and GPR are considered stationary and not cointegrated with the remaining variables. This paragraph tests for Granger causality in models that are estimated without assuming that $\beta_5 = \beta_6 = 0$ in equation (5), and $\lambda_i = 0$ for the CCI and GPR in equation (4), even though such assumptions oppose the nature of the cointegrating relationship assumed in paragraph 7.1. These tests, however, will demonstrate if the p-values in 7.1 are heavily reliant on the model assumptions.

Unrestricted model tests are presented in Table 8. In contrast with the findings in paragraph 7.1, no Granger causality is found for bonds with a maturity of 3 months. However, the results in 10 models for maturities of 2 up to 30 years still indicate Granger causal effects of the GPR index with at least 95% confidence. As in paragraph 7.1, the Granger causal effect is more notable in models with 3 or 4 lags. Despite the vastly deviating assumptions, the suggested effect of the GPR index on bond yields in Table 5 seems comparatively consistent.

Table 9 displays the p-values of tests for IRS rates, which still display p-values for the 6FL IRS rates with at least 99% confidence in nearly all cases. Analogous to the outcomes obtained for bonds, the evidence in Tables 5 and 6 regarding a relationship between the GPR index and 6FL IRS is not contradicted and remains consistent under deviating assumptions.

Table 9 *Granger causality tests for IRS rates with no restrictions.*

	2 lags		3lags		4lags	
	6FL	3FL	6FL	3FL	6FL	3FL
1y	0.001***	0.322	0.013**	0.577	0.004***	0.743
2y	0.003***	0.432	0.003***	0.304	0.002***	0.285
3y	0.002***	0.586	0.001***	0.374	0.000***	0.339
4y	0.004***	0.632	0.002***	0.282	0.000***	0.255
5y	0.007***	0.631	0.003***	0.236	0.000***	0.204
6y	0.005***	0.042**	0.000***	0.090	0.000***	0.095
7y	0.026**		0.010**		0.000***	
8y	0.008***	0.907	0.001***	0.080	0.000***	0.087
9y	0.009***	0.907	0.001***	0.082	0.000***	0.1
10y	0.057	0.162	0.024**	0.045**	0.001***	0.000***
12y	0.31	0.34	0.000***	0.074	0.000***	0.023**
15y	0.285	0.776	0.000***	0.103	0.000***	0.084
20y	0.5	0.551	0.000***	0.234	0.000***	0.239
25y	0.022**	0.349	0.000***	0.541	0.000***	0.619
30y	0.107	0.214	0.000***	0.188	0.000***	0.188

Note: The table lists p-values of Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on IRS as dependent variable are in each case equivalent to over 99,9% confidence.

However, for 3FL IRS rates, the amount of significant results has declined from 16 models to just 3 models. Since the samples are identical to those in paragraph 7.1, the fact that this deterioration is only seen in 3FL IRS rates is noteworthy. The p-values for 3FL IRS rates in Table 7 seem, thus, particularly reliant on the model assumptions. Nevertheless, given the strongly deviating assumptions in this paragraph, the suggestive evidence for a relationship between the GPR index and target variables, presented in paragraph 7.1, appears to be consistent and deserves further analysis.

7.2.2. VIX

Replacing the CCI by the VIX has been considered necessary as the first is not available for all subjects, leading to a reduction in sample size and an increase in weighting towards developed economies. Furthermore, changing the measure for market expectations could potentially impact the predictive performance of the GPR index.

The performance of the GPR index is evaluated in Tables 10 and 11, which display increased amounts of observations in each of the tested panels. In Table 10, still 9 cases provide 95% and 99% confident Granger causality in bonds for maturities of 2 years and longer. This is consistent with the results presented in paragraph 7.1 and the unrestricted model performance in 7.2.1.

In Table 11, p-values for 6FL IRS rates remain significant in nearly all cases with 3 and 4 lags included in the model, with many cases achieving 99% confidence. Models with 2 lags also provide evidence of Granger causality, although with a reduced number of significant p-values relative to models with more lags. The results for 6FL rates in paragraph 7.1 are consequently consistent in both robustness test types. Moreover, performance in 3FL IRS rates is comparable to the results in paragraph 7.1, with 19 significant cases of Granger causality, while models with 2 lags do reveal few Granger causal effects. These findings contradict the deterioration of Granger causal evidence in 7.2.1 for models with deviating assumptions.

Table 10 *Granger causality tests for bond yields with VIX.*

	2 lags		3 lags		4 lags	
	p	obs	p	obs	p	obs
1M	0.235	4364	0.389	4246	0.41	4128
3M	0.187	6525	0.198	6350	0.277	6175
6M	0.391	5799	0.455	5641	0.491	5483
1Y	0.453	7097	0.607	6888	0.783	6680
2Y	0.529	8195	0.043**	7960	0.021**	7726
5Y	0.121	9023	0.009***	8770	0.005***	8518
10Y	0.241	9299	0.052*	9040	0.028**	8782
20Y	0.21	4805	0.022**	4656	0.005***	4509
30Y	0.081	4894	0.000***	4745	0.000***	4598

Note: The table lists Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on bond yield as the dependent variable are in each case equivalent to over 99,9% confidence.

In summary, the full sample results appear robust to the inclusion of new types of economies in the panel and the increase in sample size, as well as the alteration of the measure of market expectations by including the VIX. Hence, the robustness tests, as presented in 7.2, lend support to the evidence presented in paragraph 7.1. However, the robustness tests with unrestricted models highlight the reliance of the Granger causal evidence in IRS rates on model assumptions, more specifically in 3FL IRS rates. We conclude that the results in paragraph 7.1 support hypothesis 1 and 2, stating that both target variables are positively related to geopolitical risk, as for both target variables a majority of the maturities displays significant Granger causality. The sign and magnitude of this relationship will be examined in paragraph 7.3.

7.3 Impulse response analysis

The Granger causality test results presented in the preceding section allow for interpretation of IRF's. It has been observed that models with 2 lags generally provide weaker evidence with less significant cases of a relationship between the GPR index and target variables, and therefore models with 2 lags are excluded in this paragraph.

IRF's have been constructed for each specification with at least 95% confidence in paragraph 7.1. Figure 6 displays the IRF's for bonds with maturities ranging from 5 to 30 years, in models with 4 lags. The bond with a 30-year maturity shows a negative sign in the first 3 months, a pattern that has not been observed in other IRF's. The sign for this impulse on the longer term is inconclusive. For the 10-year bond, the confidence intervals hint on a likely positive sign. The IRFs for 5- and 20-year maturities display a clearer positive sign, as the 95% confidence intervals in Figure 6 lie above the horizontal line at approximately lag 4. Although the effect of the GPR index on the 5-year maturity bond is relatively weak, the IRF for the 20-year maturity bond shows that a one SD innovation of the GPR index is related to a 0.02 percentage point increase in the bond yield 4 months forward in time, which is economically significant. In unreported models with 3 lags, the impulse response magnitude and confidence intervals are similar to the pattern presented in Figure 6, with 2 cases having a clear positive sign where the 95% intervals remain above the horizontal line from the fourth lag and onwards. In summary, the IRF analysis for bonds suggests a positive sign for the relationship with the GPR index. The IRFs display, however, no consistent positive sign in each specification.

Figure 7 portrays the IRF's for 6FL IRS rates with a 6-year maturity. A significantly positive sign can be deducted in the model with 3 lags, as the confidence intervals remain above the horizontal line from the onset of the impulse at the third lag, and onwards. In particular, the IRF for the 3-lag model indicates that the IRS rate increases by 0.02 percentage points in response to a one SD innovation of the GPR index. Nevertheless, the sign is ambiguous in the 6-year IRS rates for specifications with 2 and 4 lags. The IRF's for other unreported 6FL maturities between 2 and 10 years, each exhibiting significant evidence of Granger causality for all lag lengths, show a similar pattern with positive signs only in 3-lag models. In contrast, maturities of 12 years and higher exhibit strictly positive signs for each lag and in each specification with at least 95% confidence. Appendix G displays the IRF's in specifications with 15 years to maturity.

Table 11 *Granger causality tests for IRS rates with VIX.*

	2lags		3 lags				4 lags			
	6FL		3FL		6FL		3FL		6FL	
	p	obs	p	obs	p	obs	p	obs	p	obs
1y	0.026**	1514	0.137	2911	0.084	1478	0.174	2817	0.073	1442
2y	0.097	2365	0.057	2198	0.016**	2309	0.017**	2142	0.018**	2253
3y	0.017**	2365	0.079	2198	0.001***	2309	0.018**	2124	0.000***	2253
4y	0.018**	2365	0.072	2268	0.000***	2309	0.006***	2193	0.000***	2253
5y	0.007***	2297	0.038**	2198	0.000***	2243	0.008***	2124	0.000***	2198
6y	0.013**	1894	0.003***	1124	0.000***	1849	0.000***	1091	0.000***	1804
7y	0.07	2365			0.002***	2309			0.000***	2253
8y	0.037**	1894	0.000***	1057	0.000***	1849	0.000***	1027	0.000***	1804
9y	0.045**	1894	0.000***	1057	0.000***	1849	0.000***	1027	0.000***	1804
10y	0.159	2365	0.000***	1969	0.007***	2309	0.000***	1902	0.000***	2253
12y	0.004***	1615	0.032**	969	0.000***	1573	0.035**	942	0.000***	1532
15y	0.003***	1723	0.000***	1374	0.000***	1678	0.000***	1335	0.000***	1633
20y	0.036**	1505	0.046**	1157	0.000***	1468	0.023**	1124	0.000***	1431
25y	0.333	1012	0.67	580	0.000***	988	0.873	562	0.000***	964
30y	0.044**	956	0.19	807	0.000***	933	0.282	783	0.000***	910

Note: The table lists Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on IRS rate as the dependent variable are in each case equivalent to over 99,9% confidence.

As for the IRF's in 3FL IRS rates, the evidence supports the sign and magnitude of the pattern in 6FL rates. The sign is strictly positive in models with 3 lags for all maturities that are Granger causal in paragraph 7.1, with confidence intervals above the horizontal line from the onset of the impulse and onwards. In specifications with 4 lags, the sign is less clear, while a positive sign is still the most likely based on the confidence intervals. Appendix G provides a comparison of the IRF's in 3FL and 6FL models with 15-year maturities.

In summary, the IRS rates show a most likely positive response to one SD innovations in the GPR index. In general, within the full sample, the evidence suggests that the relationship of both bonds and IRS rates and the GPR index could indeed be positive. This finding is clearest in models with 3 lags, while the results in other models do not contradict this sign. Nevertheless, hypothesis 1 and 2 have to be rejected, as the positive signs are not consistently found in each case.

Table 12 *Granger causality tests for bonds in advanced and non-advanced economies.*

		2 lags		3lags		4lags	
		p	obs	P	obs	p	obs
advanced	1M	0.023**	2499	0.039**	2433	0.165	2367
	3M	0.007***	3248	0.004***	3164	0.003***	3080
	6M	0.086	2835	0.212	2761	0.113	2687
	1Y	0.054	3237	0.153	3152	0.092	3067
	2Y	0.081	4694	0.101	4573	0.089	4452
	5Y	0.203	4711	0.007***	4590	0.005***	4469
	10Y	0.127	4831	0.012**	4707	0.004***	4583
	20Y	0.417	2952	0.000***	2871	0.000***	2790
	30Y	0.000***	3402	0.000***	3311	0.000***	3220
non-advanced	1M	0.239	811	0.368	786	0.475	761
	3M	0.112	1195	0.204	1159	0.217	1123
	6M	0.404	1095	0.466	1061	0.508	1027
	1Y	0.181	1581	0.526	1519	0.418	1458
	2Y	0.047**	1652	0.099	1591	0.079	1531
	5Y	0.001***	2089	0.005***	2018	0.006***	1948
	10Y	0.003***	2046	0.012**	1977	0.005***	1909
	20Y	0.007***	912	0.004***	870	0.007***	830
	30Y	0.221	698	0.324	663	0.227	629

Note: The table lists Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on bond yield as the dependent variable are in each case equivalent to over 99,9% confidence.

8. Country-specific risk and economic development

The findings in Section 7 indicate the potential for a link between the GPR index and both target variables. Although hypotheses 1 and 2 were rejected due to the ambiguous sign in the overall sample, the relationship identified in Section 7 requires further investigation. Given that the target variables introduce changes in the sample structure for each model, paragraph 8.1 seeks to further explore the existence of Granger causality by examining if advanced and non-advanced economies respond differently to geopolitical risk. In paragraph 8.2, we assess hypothesis 3 by analyzing regional samples and employing country-specific geopolitical risk indexes that relate to three major geopolitical actors: the U.S., Russia and China.

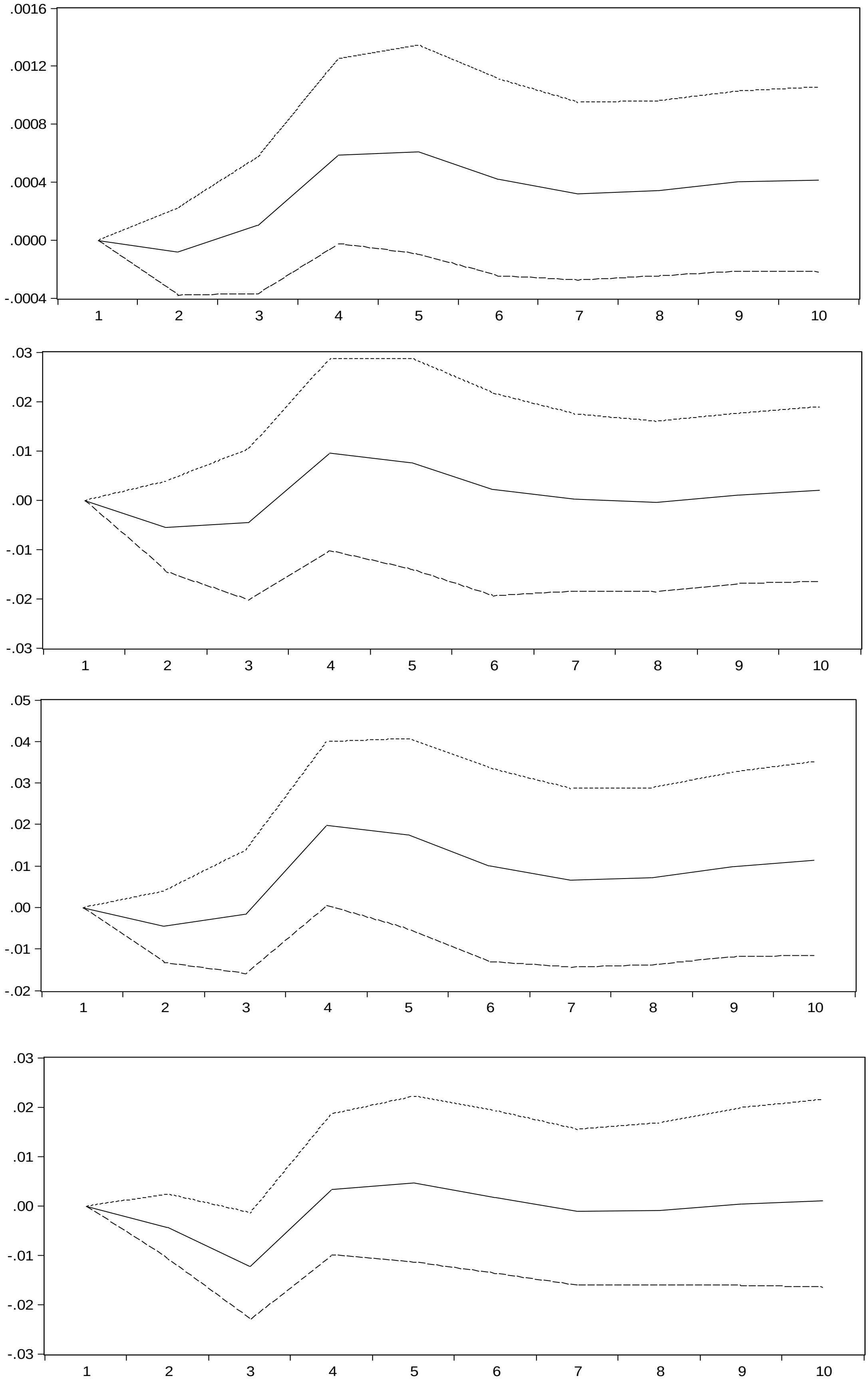

Figure 6 Impulse response for bond specifications with 4 lags and 5, 10, 20 and 30-year maturities, consecutively.

8.1 Advanced and non-advanced economies

In this paragraph the sample is divided in two groups, advanced and non-advanced economies, as designated in Appendix A. Table 12 displays Granger causality tests for bonds in both separate groups. Advanced economies exhibit Granger causality in 6 out of 9 maturities and in 14 specifications with 99% confidence in most cases, which aligns with the finding in Table 5 for the full sample. Non-advanced economies, however, demonstrate less significant p-values. Yet, still 4 maturities and 9 cases demonstrate Granger causality with 95% confidence and higher. These 95% confident results emerge for bonds with maturities between 2 and 30 years, consistent with the pattern in the full sample.

Table 13 *Granger causality tests for 3FL IRS rates in non-advanced economies.*

	2 lags		3 lags		4 lags	
	p	obs	p	obs	p	obs
1y	0.307	882	0.259	844	0.247	807
2y	0.193	801	0.065	766	0.048**	732
3y	0.22	801	0.111	766	0.065	732
4y	0.237	801	0.08	766	0.039**	732
5y	0.213	801	0.056	766	0.022**	732
6y	0.121	390	0.007***	379	0.004***	368
8y	0.063	390	0.005***	379	0.005***	368
9y	0.057	390	0.004***	379	0.004***	368
10y	0.12	531	0.002***	504	0.002***	478
15y	0.016	403	0.001***	393	0.001***	383
20y	0.111	344	0.146	335	0.082	326

Note: The table lists Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on the IRS rate as dependent variable are in each case equivalent to over 99,9% confidence.

Test results for IRS rates in advanced economies are in Appendix H. Advanced economies demonstrate strong performance of the GPR index, with Granger causality found with 95% confidence in all 6FL specifications and for 3FL models with 3 or 4 lags in each case. In contrast, non-advanced economies do not exhibit Granger causality in 6FL IRS rates. Results for 3FL models in non-advanced economies can be found in Table 13. Although sample sizes are relatively low, significant p-values are presented in 13 specifications and 8 maturities. Compared to the 16 significant cases in the full sample, the amount is reduced by 3.

In summary, the p-values indicate that the outcomes for 3FL rates in Table 6 do not rely solely on advanced economies, but extend to non-advanced economies as well. The results for 6FL rates, on the other hand, are not consistently found in non-advanced economies. Hence, the results in Table 7 could be driven solely by advanced economies in the full sample. As regards the bond yields, both advanced and non-advanced economies demonstrate a relationship between the GPR index and bond yields. However, despite 3 maturities with Granger causality in non-advanced economies, hypothesis 1 requires that the bond maturities show significant Granger causality by majority. Hypothesis 2 can neither be accepted, as the relationship between the GPR index and 6FL IRS rates is not observed consistently in non-advanced economies. Nonetheless, insufficiency of the evidence for a positive sign of the relationship, found in the full sample, already led to the rejection of hypothesis 1 and 2.

8.2 Country-specific risk

In this paragraph, the sample is separated into 4 regional groups of Member States from the United Nations (United Nations, 2017), with the objective to examine the link of bond yields with both the general GPR index, and the country-specific indexes from Russia, China and the U.S.

Despite the specific index included, few significant results are obtained in models with 2 lags in each group, with Latin American subjects yielding nearly no significant Granger causality for any model type. Nevertheless, in other groups significant results are found in models with 3 lags, and generally replicated in models with 4 lags, consistent with the full sample evidence. Test outcomes in models with 4 lags are presented in Table 14. The global index produces fewer significant results in each group compared to the full sample. Yet, the general GPR index still exhibits 4 maturities and 7 specifications of Granger causality in Western subjects. In Asia and the Pacific, 2 maturities and 3 specifications exhibit Granger causality. In 1 case of Eastern European subjects, Granger causality is presented with 99% confidence. In general, regional Granger causal evidence for the global index corresponds to unreported IRF's with likely positive signs, with in several cases strictly positive signs with 95% confidence. This finding supports the suggested positive sign in the full sample results.

Regarding country-specific indexes, the response of bond yields in regional groups appears relatively strong, with bonds in Western subjects showing the best performance. In this group, maturities between 2 and 30 years are Granger causal at 95% for all four indexes - the global, United States, Chinese and Russian index. The U.S. specific index performs slightly superior to the general index, exhibiting 10 Granger causal cases. Hence, Western subjects have an amplified response to geopolitical risk for the major actor with a geographical connection to their region. In each Granger causal case, impulse responses are strictly positive, with the Chinese and Russian GPR index displaying relatively larger responses. Appendix I displays IRF's for each index in Western bonds with 30-year maturities.

Table 14 *Granger causality tests in regional groups for bonds in models with 4 lags.*

	mat	Obs.	general	U.S.	China	Russia
Western	1M	2549	0.127	0.034**	0.028**	0.338
	3M	3691	0.1	0.099	0.16	0.21
	6M	3225	0.419	0.305	0.166	0.59
	1Y	3236	0.449	0.497	0.059	0.01**
	2Y	4298	0.049**	0.091	0.000***	0.000***
	5Y	4481	0.023**	0.049**	0.000***	0.023**
	10Y	4677	0.562	0.083	0.934	0.000***
	20Y	2593	0.000***	0.000***	0.000***	0.000***
	30Y	3232	0.000***	0.000***	0.000***	0.000***
Asia and the Pacific	2Y	2326	0.496	0.666	0.434	0.17
	5Y	2577	0.06	0.114	0.035**	0.001***
	10Y	2771	0.064	0.163	0.135	0.000***
	20Y	1560	0.000***	0.001***	0.362	0.003***
	30Y	1166	0.282	0.187	0.254	0.001***
Eastern Europe	2Y	775	0.224	0.415	0.579	0.002***
	5Y	995	0.991	0.893	0.665	0.007***
	10Y	992	0.689	0.681	0.123	0.000***
	20Y	186	0.000***	0.000***	0.003***	0.000***

Note: The table lists p-values of Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on bond yield as dependent variable are in each case equivalent to over 99,9% confidence.

As for Asia and the Pacific, the Chinese index does not outperform the global index, showing only 2 Granger causal specifications, which is equal to the global index. The Russian GPR index has particularly high performance, as in each other group, with at least 4 bond maturities showing 99% confidence. Furthermore, bonds in Eastern European subjects respond particularly well to the Russian index with 10 Granger causal specifications, implying that bonds in Eastern European subjects have a higher response to their regional geopolitical actor relative to the global index.

As stated, the Russian index performs particularly well within the sample. Figure 8 presents IRF's for the Russian index in 20-year maturity bonds, demonstrating that the confidence intervals are in each IRF strictly above the horizontal line. The presented impulse responses of bond yields to a one SD innovation of the Russian GPR index are equivalent to an increase of 0.05 percentage points or higher in each group, with the magnitude being particularly high for Eastern European countries. These responses are economically significant.

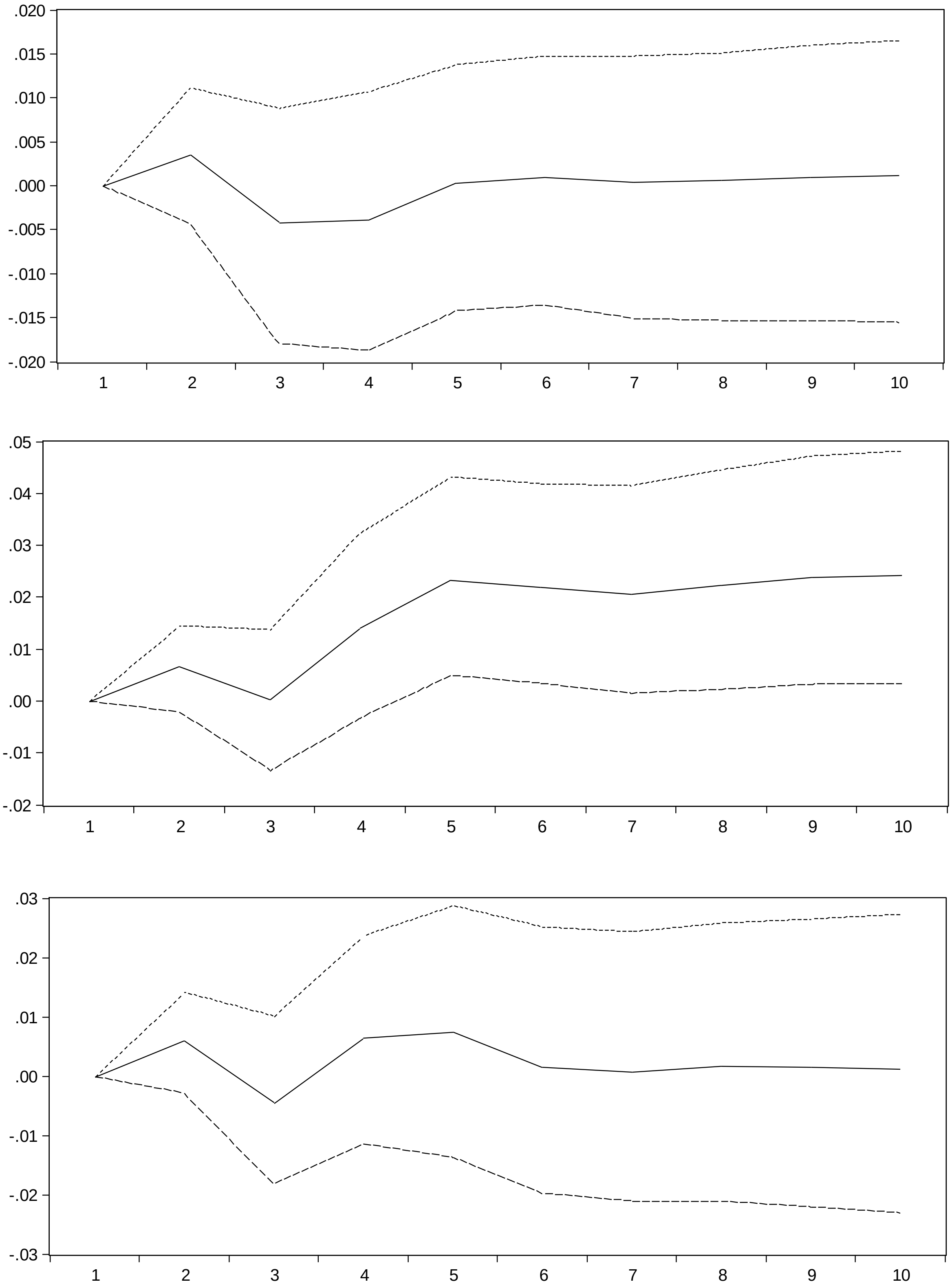

Figure 7 Impulse response for 6FL IRS with 6-year maturity with 2, 3 and 4 lags, consecutively.

In summary, the results in the regional groups suggest that bond yields in Western subjects are positively related to the global, USA and China-specific indexes. The global index, however, has relatively weak performance in the remaining groups. On top of that, hypothesis 3 must be rejected, due to no superior performance of the Chinese index over the global index in Asia and the Pacific. Still, the evidence for the relationship between the Russian GPR and bonds is notable, having a large magnitude in the Western, Asia Pacific and Eastern European groups.

9. Conclusion and discussion

9.1 Conclusion

This study examines the following research question: 'How are government bonds and plain vanilla interest rate swaps across the 45 largest economies and 23 currency areas related to geopolitical risk in the short run in the period 1990-2022?'. To address this research question, a panel VECM framework is employed, incorporating various GPR indexes by Caldara and Iacoviello (2022). Based on international financial theories, it is hypothesized that both bonds and IRS rates have a positive relationship with geopolitical risk in the short run.

The findings suggest that a positive and economically significant relationship may exist in the short run between geopolitical risk and both sovereign bond yields and plain vanilla IRS rates. Although the results were too inconsistent to confirm the positive sign, a relationship has been found in separate groups of advanced economies and non-advanced economies, and both in models with the CCI and VIX included. The evidence is the most prominent in models with 3 or 4 lags, while models with 2 lags show few significant results. This implies that geopolitical risk would have a lagged positive link with both bond yields and IRS, requiring several months to appear.

This thesis rejects the hypothesis that regional groups have an amplified response to risk of major geopolitical actors in their region, as this pattern is not consistently found in each region. Still, in the group of Western economies the responses for geopolitical risk related to China, the Russia and the U.S. show that country-specific indexes can capture geopolitical risks that are relevant for determination of bond yields. Furthermore, geopolitical risk related to Russia is strongly related to bond yields in several regional groups, indicating that despite geographical factors, key geopolitical conflicts are an important driver of geopolitical risk for bonds in both geographically connected and less connected economies.

Although the hypotheses are rejected, the results of this thesis suggests that geopolitical acts and or threats lead to raised interest rates. This could indeed be due to inflationary effects caused by disturbed supply chains and government spending for military activities (Caldara et al, 2022), flight-to-safety capital flows (Forbes and Warnock (2012), or central banks raising interest rates in forward looking policies (Clarida, Gali & Gertler, 1998). The amplified effect for Russia-related geopolitical risk suggests that the Russo-Ukrainian war has in particular lead to these financial market implications. However, further research is needed to draw definitive conclusions.

Summarizing, the answer to the research question is that the evidence from this panel data suggests that, in the short-run, government bond yields and IRS rates positively related to geopolitical risk. The relationship with geopolitical risk is the most pronounced in Western and advanced economies, while the GPR index still provides cases of Granger causality in the remaining subjects. The evidence indicates as well that geopolitical risk related to the Russo-Ukrainian War could be a crucial driving factor in the overall results.

9.2 Limitations and future research

There are several limitations of this study that deserve notice. Firstly, the base model assumes 5 variables to be non-stationary and cointegrating, while deviating arguments can be made in the empirical analysis provided in Section 5. This thesis assumes the existence of only a single cointegrating equation in each model, while examination of models with multiple cointegrating equations could capture discontinuities in the long-run equilibrium, such as interventions by policymakers and systematic shocks. The results may therefore suffer from spuriousness due to these discontinuities. In particular, the present study's sample captures recent years with exceptional inflation and rising interest rates. Interpretation of the Russo-Ukrainian War as a driving factor in these interest rate rises needs caution. The sample also includes an earlier period of exceptionally low interest rates, preceding the aforementioned inflation and interest rate rises. Additionally, the Russo-Ukrainian War has coincided with another shock that has been suggested to disrupt supply chains and cause inflation: the Covid-19 pandemic.

Furthermore, while the imposed restrictions on the cointegrating equation appear robust to the tests in paragraph 7.2.1, excluding the stationary variables GPR, CCI and VIX from the cointegrating equation involves the loss of information on their long-run relationship with the cointegrating variables. One alternative is to use artificial vectors to address a combination of $i(0)$ and $i(1)$ variables in the cointegrating equation (Levtchenkova, Pagan & Robertson, 1998).

Moreover, relying solely on the VIX in the models in paragraph 8.2 is suboptimal, as this variable is not nationally determined, in contrast to the national CCI, and relates to the S&P500, which is a U.S.-located stock index. Additionally, the lag length chosen in the models may not be optimal, as several model selection tests provided different lag lengths. Finally, the panel data in this thesis is unbalanced. If data in periods without observations is not missing at random, this feature could induce bias, despite the robustness tests performed to address this limitation.

Several recommendations can be made for future research on the relationship between geopolitical risk and interest rate products. Employing a spatial VAR model (spVAR) can enable a detailed analysis of the spill-over or regional effects between countries. Besides, future studies could investigate the impact of geopolitical risk on market volatility by adopting models appropriate for variance analysis. Finally, studies could concentrate on quantifying the magnitude of the impact of geopolitical risk on interest rates. This proposed research can offer valuable insights into the multidimensional relationship between geopolitical risk and financial markets, and contribute to improved risk management policies.

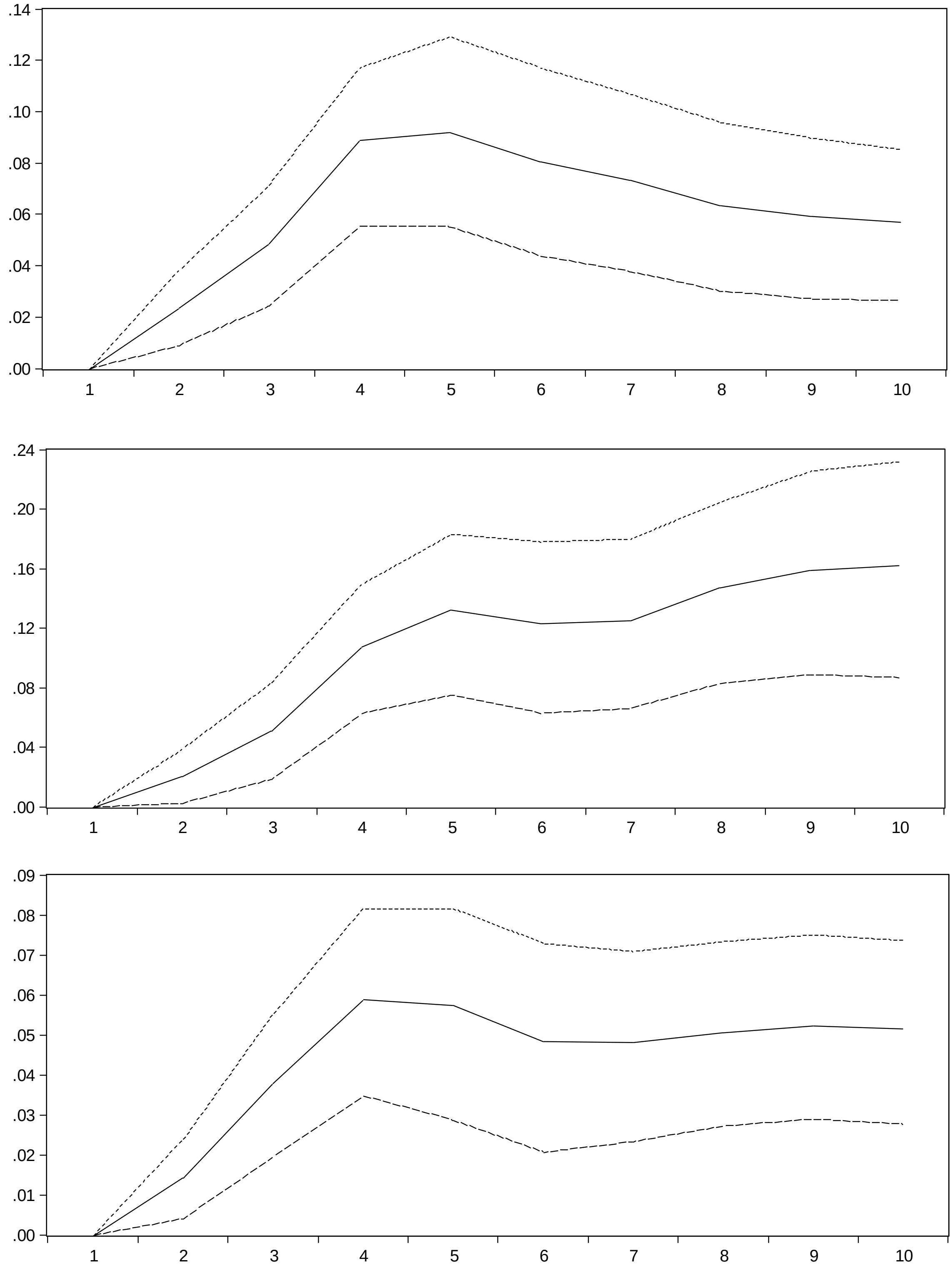

Figure 8 Impulse response to Russian GPR index for bonds with 10-year maturity and 4 lags. Western, Eastern European and Asian-Pacific groups, consecutively.

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11. Appendix

Appendix A *Subject list.*

subject	id	IRS	Adv	UN	CCI	subject	id	IRS	Adv.	UN	CCI
United States	1	1	1	1	1	Thailand	24	1	0	2	1
China	2	1	0	2	1	Israel	25	1	1	1	1
Japan	3	1	1	2	1	Ireland	26	0	1	1	1
Germany	4	0	1	1	1	Norway	27	1	1	1	0
India	5	1	0	2	0	Egypt	28	0	0	3	0
United Kingdom	6	1	1	1	1	Bangladesh	29	0	0	2	0
France	7	0	1	1	1	Malaysia	30	0	0	2	0
Canada	8	1	1	1	0	Singapore	31	0	1	2	0
Russia	9	1	0	4	1	Vietnam	32	0	0	2	0
Italy	10	0	1	1	1	South Africa	33	1	0	3	1
Brazil	11	0	0	5	1	Philippines	34	1	0	2	0
South Korea	12	1	1	2	1	Denmark	35	1	1	1	1
Mexico	13	0	0	5	1	Pakistan	36	0	0	2	0
Spain	14	0	1	1	1	Hong Kong	37	1	1	2	0
Indonesia	15	0	0	2	1	Colombia	38	0	0	5	1
Netherlands	16	0	1	1	1	Chile	39	0	0	5	1
Türkiye	17	1	0	1	1	Romania	40	0	0	4	0
Taiwan	18	1	1	2	1	Czechia	41	1	1	4	1
Switzerland	19	1	1	1	1	Finland	42	0	1	1	1
Poland	20	1	1	4	1	Portugal	43	0	1	1	1
Argentina	21	0	0	5	1	Greece	44	0	1	1	1
Sweden	22	1	1	1	1	Hungary	45	1	0	4	1
Belgium	23	0	1	1	1	Euro area	99	1	1	1	1

Note: IRS denotes subjects in the IRS sample. Adv states if the economy is advanced or non-advanced. UN defines the regional group. Group 1 are Western States, group 2 Asia-Pacific States, group 3 African States, group 4 Eastern European States, group 5 Latin American and Caribbean States. Taiwan and Hong Kong are considered according to the regional group of China.

Appendix B *Unit root tests in first differences for non-target variables.*

		No cons			cons			
	Method	LLC	ADFF	PPF	LLC	IPS	ADFF	PPF
GPR	Stat	-106.119	7051.420	3354.43	-112.139	-108.368	6660.46	957.875
	P	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
IPI	Stat	-75.982	5678.88	6706.68	-72.639	-83.154	4283.52	3939.23
	P	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
MSCI	Stat	-110.782	7648.34	8291.63	-125.126	-110.987	5830.85	6326.53
	P	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
ER	Stat	-111.38	6779.09	7409.12	-128.437	-112.767	5985.1	6244.48
	P	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
CCI	Stat	-40.363	2040.3	1137.39	-35.959	-39.859	1583.94	708.515
	P	0.000***	0.000***	0.000**	0.000***	0.000***	0.000***	0.000***
CPI	Stat	-16.805	968.302	5206.02	-20.062	-27.187	1656.21	4995.54
	P	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
VIX	Stat	-141.189	8717.85	9212.2	-176.648	-150.111	7901.13	7826
	P	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

Note: ADFF denotes the Fisher-type ADF test, PPF the Phillips-Perron – Fisher test, LLC the Levin, Lin and Chu test and IPS the Im, Pesaran and Shin test. The LLC statistic assumes common unit root processes, while the IPS, ADF and PPF assume individual unit root processes. ** and *** denote tests that reject the null with 95 and 99% confidence.

Appendix C *Unit root tests in levels for bonds.*

	No constant			Constant			
	LLC	ADFF	PPF	LLC	IPS	ADFF	PPF
1M	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
3M	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
6M	0.000***	0.000***	0.000***	0.004***	0.000***	0.000***	0.000***
1Y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
2Y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
5Y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
10Y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
20Y	0.000***	0.002***	0.001***	0.000***	0.0028***	0.002***	0.052
30Y	0.000***	0.004***	0.000***	0.000***	0.014**	0.136	0.378

Note: ADFF denotes the Fisher-type ADF test, PPF the Phillips-Perron – Fisher test, LLC the Levin, Lin and Chu test and IPS the Im, Pesaran and Shin test. The LLC statistic assumes common unit root processes, while the IPS, ADF and PPF assume individual unit root processes. ** and *** denote tests that reject the null with 95 and 99% confidence.

Appendix D *Unit root tests for IRS in levels.*

		No constant			Constant			
	mat	LLC	ADFF	PPF	LLC	IPS	ADFF	PPF
3FL	1y	0.000***	0.000***	0.000***	0.000***	0.001***	0.000***	0.001***
	2y	0.000***	0.022**	0.067	0.021**	0.026**	0.002***	0.034**
	3y	0.000***	0.022**	0.054	0.009***	0.022**	0.001***	0.018**
	4y	0.000***	0.02	0.039**	0.005***	0.017**	0.001***	0.013**
	5y	0.000***	0.025**	0.035**	0.004***	0.014**	0.000***	0.011**
	6y	0.008***	0.287	0.294	0.081	0.053	0.01	0.021**
	8y	0.01	0.319	0.367	0.052	0.022***	0.006***	0.014**
	9y	0.006***	0.25	0.317	0.049**	0.054	0.056	0.006***
	10y	0.000***	0.024**	0.009***	0.002***	0.012**	0.023**	0.083
	12y	0.029**	0.339	0.296	0.09	0.24	0.292	0.273
	15y	0.001***	0.135	0.131	0.005***	0.002***	0.000***	0.002***
	20y	0.002***	0.18	0.153	0.007***	0.008***	0.001**	0.004***
	25y	0.121	0.281	0.312	0.14	0.023**	0.028**	0.029**
	30y	0.024**	0.161	0.133	0.097	0.083	0.121	0.093
6FL	1y	0.001***	0.024**	0.059	0.772	0.242	0.162	0.683
	2y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	3y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	4y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	5y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	6y	0.000***	0.000***	0.000***	0.000***	0.001***	0.001***	0.007***
	7y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.001***
	8y	0.000***	0.000***	0.000***	0.000***	0.002***	0.002***	0.018**
	9y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	10y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	12y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	15y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	20y	0.000***	0.000***	0.000***	0.000***	0.001***	0.001***	0.007***
	25y	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.001***
	30y	0.000***	0.000***	0.000***	0.000***	0.002***	0.002***	0.018**

Note: ADFF denotes the Fisher-type ADF test, PPF the Phillips-Perron – Fisher test, LLC the Levin, Lin and Chu test and IPS the Im, Pesaran and Shin test. The LLC statistic assumes common unit root processes, while the IPS, ADF and PPF assume individual unit root processes. ** and *** denote tests that reject the null with 95 and 99% confidence.

Appendix E C*ointegration tests for bonds.*

		1M	3M	6M	1Y	2Y	5Y	10Y	20Y	30Y
Pedroni	Mod. PP	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	PP	0.305	0.084*	0.000***	0.000***	0.003***	0.000***	0.000***	0.000***	0.000***
	ADF	0.026**	0.000***	0.000***.	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
no constant	Mod. PP	0.000***	0.000***	0000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	PP	0.298	0.278	0.000***	0.000***	0.051	0.000***	0.001***	0.000***	0.000***
	ADF	0.097*	0.17	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Trend	Mod. PP	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	PP	0.004***	0.081*	0.005***	0.24	0.01**	0.096*	0.115	0.143	0.017***
	ADF	0.056*	0.003***	0.000***	0.022**	0.024**	0.11	0.283	0.349	0.019***
Demean	Mod. PP	0.000***.	0.003***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	PP	0.458	0.332	0.046**	0.049**	0.000***	0.012**	0.006***	0.049**	0.059*
	ADF	0.354	0.034	0.000***	0.428	0.000***	0.408	0.184	0.361	0.146
Kao	Mod. DF	0.000***.	0.003***	0.000***	0.000***	0.001***	0.000***	0.000***	0.000***	0.002***
	DF	0.01**	0.332	0.477	0.000***	0.239	0.118	0.069*	0.365	0.03**
	ADF	0.079**	0.034**	0.175	0.000***	0.001***	0.000***	0.001***	0.036**	0.254
	Unadj. Mod. DF	0.000***	0.038**	0.086*	0.000***	0.000***	0.006***	0.037**	0.003***	0.051**
	Unadj. DF	0.003***	0.454	0.107	0.000***	0.455	0.416	0.475	0.487	0.107
demean	Mod. DF	0.000***	0.002***	0.284	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	DF	0.074*	0.338	0.045**	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	ADF	0.165	0.021**	0.137	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	Unadj. Mod. DF	0.000***	0.023**	0.27	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	Unadj. DF	0.024**	0.175	0.005***	0.000***	0.000***	0.02**	0.001***	0.000***	0.000***
Westerlund		0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Trend		0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
All panels		0.013**	0.005***	0.004***	0.002***	0.002***	0.002***	0.002	0.014**	0.007***
Demean		0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

Note: The table denotes p-values of cointegration tests with automatic lag selection. Tests with predetermined lags provide well comparable results. ** and *** denote tests that reject the null with 95 and 99% confidence. PP denotes Phillips-Perron tests, (A)DF denotes (Augmented) Dickey-Fuller tests. PP denotes Phillips-Perron tests, (A)DF denotes (Augmented) Dickey-Fuller tests.

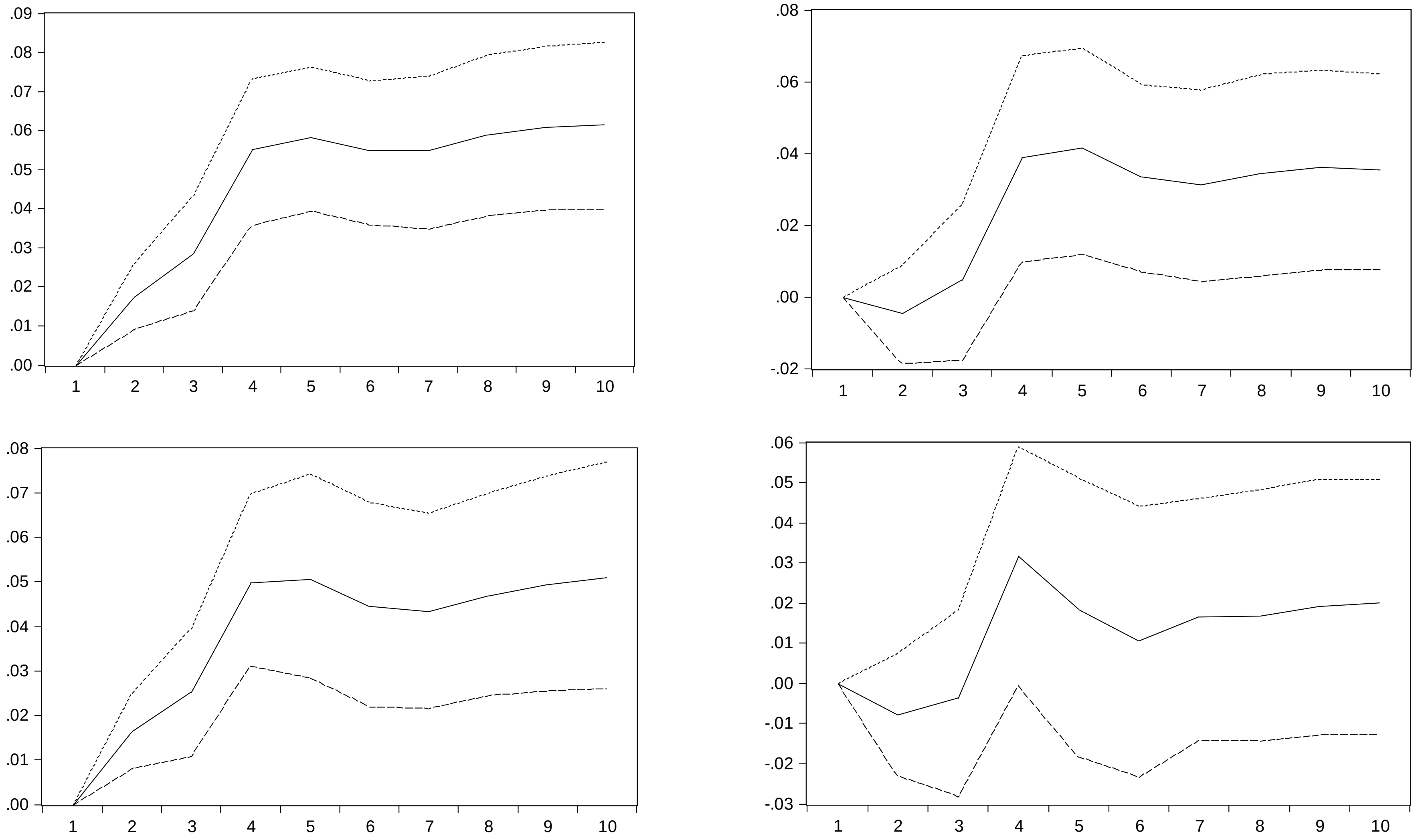
Appendix F C*ointegration tests for IRS rates.*

		1Y		2Y		3Y		4Y		5Y		6Y		7Y	8Y	
	stat	6FL	3FL	6FL	3FL	6FL	3FL	6FL	3FL	6FL	3FL	6FL	3FL	6FL	6FL	3FL
Pedroni	Mod. PP	0.011**	0.000***	0.122	0.000***	0.164	0.000***	0.183	0.000***	0.348	0.000***	0.006***	0.017**	0.277	0.006***	0.01**
	PP	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	ADF	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
No con-	Mod. PP	0.101	0.000***	0.005***	0.000***	0.006***	0.000***	0.007***	0.000***	0.012**	0.000***	0.000***	0.001***	0.032**	0.000***	0.001***
stant	PP	0.000***	0.000***	0.000***	0.003***	0.000***	0.006***	0.000***	0.006***	0.000***	0.01**	0.000***	0.000***	0.000***	0.000***	0.000***
	ADF	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
trend	Mod. PP	0.002***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	PP	0.018**	0.006***	0.363	0.188	0.466	0.052*	0.419	0.045**	0.448	0.022**	0.18	0.327	0.445	0.149	0.322
	ADF	0.000***	0.000***	0.123	0.348	0.264	0.348	0.323	0.301	0.255	0.265	0.109	0.446	0.279	0.084*	0.211
demean	Mod. PP	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.14	0.127	0.000***	0.039	0.001***
	PP	0.274	0.243	0.203	0.316	0.381	0.329	0.468	0.177	0.157	0.219	0.000***	0.01**	0.282	0.001***	0.255
	ADF	0.000***	0.076*	0.007***	0.019**	0.064*	0.035**	0.192	0.063*	0.026**	0.074*	0.000***	0.007	0.438	0.000***	0.251
Kao	Mod. DF	0.000***	0.057**	0.001***	0.086*	0.007***	0.135	0.02**	0.194	0.000***	0.257	0.000***	0.149	0.051	0.000***	0.234
	PP	0.000***	0.001***	0.000***	0.286	0.001***	0.237	0.003***	0.194	0.000***	0.151	0.000***	0.026**	0.011**	0.000***	0.055*
	ADF	0.000***	0.002***	0.197	0.329	0.292	0.349	0.359	0.29	0.01**	0.236	0.000***	0.44	0.389	0.000***	0.444
	Unadj. Mod. DF	0.000***	0.053*	0.000***	0.044	0.002***	0.069*	0.007***	0.1	0.000***	0.145	0.000***	0.143	0.029**	0.000***	0.228
	Unadj. DF	0.000***	0.001***	0.000***	0.355	0.000***	0.312	0.000***	0.273	0.000***	0.22	0.000***	0.024***	0.004***	0.000***	0.053*
demean	Mod. DF	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.303	0.000***	0.000***	0.036**
	PP	0.000***	0.154	0.1	0.08*	0.033**	0.089*	0.009***	0.101	0.017**	0.109	0.417	0.172	0.000***	0.262	0.474
	ADF	0.008***	0.276	0.456	0.103	0.304	0.079*	0.203	0.127	0.345	0.159	0.02**	0.377	0.08*	0.043**	0.206
	Unadj. Mod. DF	0.000***	0.000***	0.007***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.007***	0.426	0.000***	0.001***	0.062**
	Unadj. DF	0.000***	0.185	0.259	0.105	0.094*	0.115	0.026**	0.124	0.036**	0.131	0.435	0.119	0.001***	0.361	0.425
Westerlund	variance ratio	0.034**	0.000***	0.085*	0.001***	0.121	0.001***	0.156	0.001***	0.182	0.001***	0.395	0.06*	0.23	0.424	0.068*
Trend	Variance ratio	0.034**	0.000***	0.013**	0.000***	0.013**	0.000***	0.012**	0.000***	0.01**	0.000***	0.052*	0.007***	0.008***	0.037**	0.005***
All	Variance ratio	0.198	0.03**	0.124	0.047**	0.147	0.049**	0.177	0.05*	0.217	0.051*	0.201	0.196	0.278	0.231	0.203
demean	Variance ratio	0.013***	0.000***	0.004***	0.001***	0.004***	0.001***	0.005***	0.001***	0.008***	0.001***	0.012**	0.066*	0.008***	0.012**	0.023**

		9Y		10Y		12Y		15Y		20Y		25Y		30Y	
	stat	6FL	3FL	6FL	3FL	6FL	3FL	6FL	3FL	6FL	3FL	6FL	3FL	6FL	3FL
Pedroni	Mod. PP	0.006***	0.008***	0.363	0.000**	0.001***	0.000***	0.000***	0.000***	0.114	0.000***	0.000***	0.244	0.003***	0.488
	PP	0.000***	0.000***	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***	0.000***	0.001***	0.005***	0.011**	0.013**	0.000***
	ADF	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.001***	0.000***
No con-	Mod. PP	0.000***	0.001***	0.079*	0.000***	0.004***	0.109	0.000***	0.431	0.11	0.192	0.023**	0.189	0.316	0.286
stant	PP	0.000***	0.000***	0.000***	0.02**	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.014	0.038**	0.036**	0.01**
	ADF	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.002***	0.001***	0.003***	0.000***
trend	Mod. PP	0.000***	0.000***	0.000***	0.000***	0.434	0.000***	0.29	0.000***	0.019**	0.000***	0.000***	0.000***	0.000***	0.017**
	PP	0.149	0.198	0.439	0.001***	0.01**	0.004***	0.019**	0.049**	0.352	0.035**	0.379	0.082*	0.401	0.299
	ADF	0.079*	0.223	0.241	0.048**	0.006***	0.011**	0.003***	0.275	0.48	0.043**	0.116	0.186	0.222	0.247
demean	Mod. PP	0.025**	0.001***	0.000***	0.000***	0.018**	0.000***	0.016***	0.000***	0.002***	0.000***	0.001***	0.000***	0.001***	0.001***
	PP	0.002***	0.256	0.275	0.168	0.463	0.026**	0.394	0.061*	0.432	0.179	0.183	0.019**	0.373	0.098*
	ADF	0.000***	0.252	0.458	0.026**	0.189	0.013**	0.003***	0.017**	0.167	0.362	0.161	0.017**	0.02**	0.084*
Kao	Mod. DF	0.000***	0.301	0.069*	0.216	0.000***	0.253	0.000***	0.184	0.000***	0.202	0.015**	0.106	0.031**	0.151
	PP	0.000***	0.083*	0.016**	0.369	0.000***	0.088*	0.000***	0.426	0.000***	0.5	0.001***	0.323	0.002***	0.437
	ADF	0.000***	0.491	0.397	0.075*	0.000***	0.496	0.000***	0.117	0.000***	0.215	0.412	0.146	0.463	0.264
	Unadj. Mod. DF	0.000***	0.299	0.055*	0.325	0.000***	0.372	0.000***	0.36	0.000***	0.000***	0.015**	0.051*	0.032**	0.066*
	Unadj. DF	0.000***	0.082*	0.011**	0.291	0.000***	0.15	0.000***	0.299	0.000***	0.106	0.001***	0.266	0.002***	0.348
demean	Mod. DF	0.000***	0.022**	0.000***	0.003***	0.149	0.078*	0.058*	0.000***	0.245	0.000***	0.053*	0.000***	0.003***	0.000***
	PP	0.23	0.467	0.000***	0.162	0.292	0.203	0.002***	0.000***	0.198	0.032**	0.437	0.000***	0.155	0.003***
	ADF	0.053*	0.181	0.035***	0.002***	0.091*	0.106	0.002***	0.000***	0.269	0.321	0.442	0.000***	0.132	0.003***
	Unadj. Mod. DF	0.000***	0.033**	0.000***	0.004***	0.185	0.035**	0.053*	0.000***	0.191	0.000***	0.004***	0.000***	0000***	0.000***
	Unadj. DF	0.313	0.496	0.000***	0.168	0.263	0.154	0.002***	0.000***	0.233	0.000***	0.262	0.000***	0.075*	0.000***
Westerlund variance ratio		0.427	0.069*	0.247	0.004***	0.339	0.037**	0.252	0.007***	0.162	0.024**	0.053*	0.102	0.132	0.088*
Trend	Variance ratio	0.032**	0.004***	0.004***	0.000***	0.151	0.001***	0.296	0.000***	0.148	0.001***	0.032**	0.016**	0.131	0.01**
All	Variance ratio	0.242	0.205	0.333	0.093*	0.257	0.185	0.242	0.11	0.224	0.133	0.172	0.248	0.226	0.233
demean	Variance ratio	0.012**	0.023**	0.011**	0.005***	0.146	0.026**	0.114	0.004***	0.069*	0.009***	0.038**	0.074*	0.086*	0.139

Note: The table denotes p-values of panel cointegration tests. Tests have been performed with automatic lag selection. Tests with predetermined lags provide well comparable results. Tests ex CPI include only the ER, MSCI and IPI variables. ** and *** denote tests that reject the null with 95 and 99% confidence. PP denotes Phillips-Perron tests, (A)DF denotes (Augmented) Dickey-Fuller tests.

Appendix G *Impulse response of IRS rate in models with 15-year maturity to a one SD innovation with 3 and 4 lags, consecutively. 6FL IRS rates are on the left, 3FL rates on the right side.*

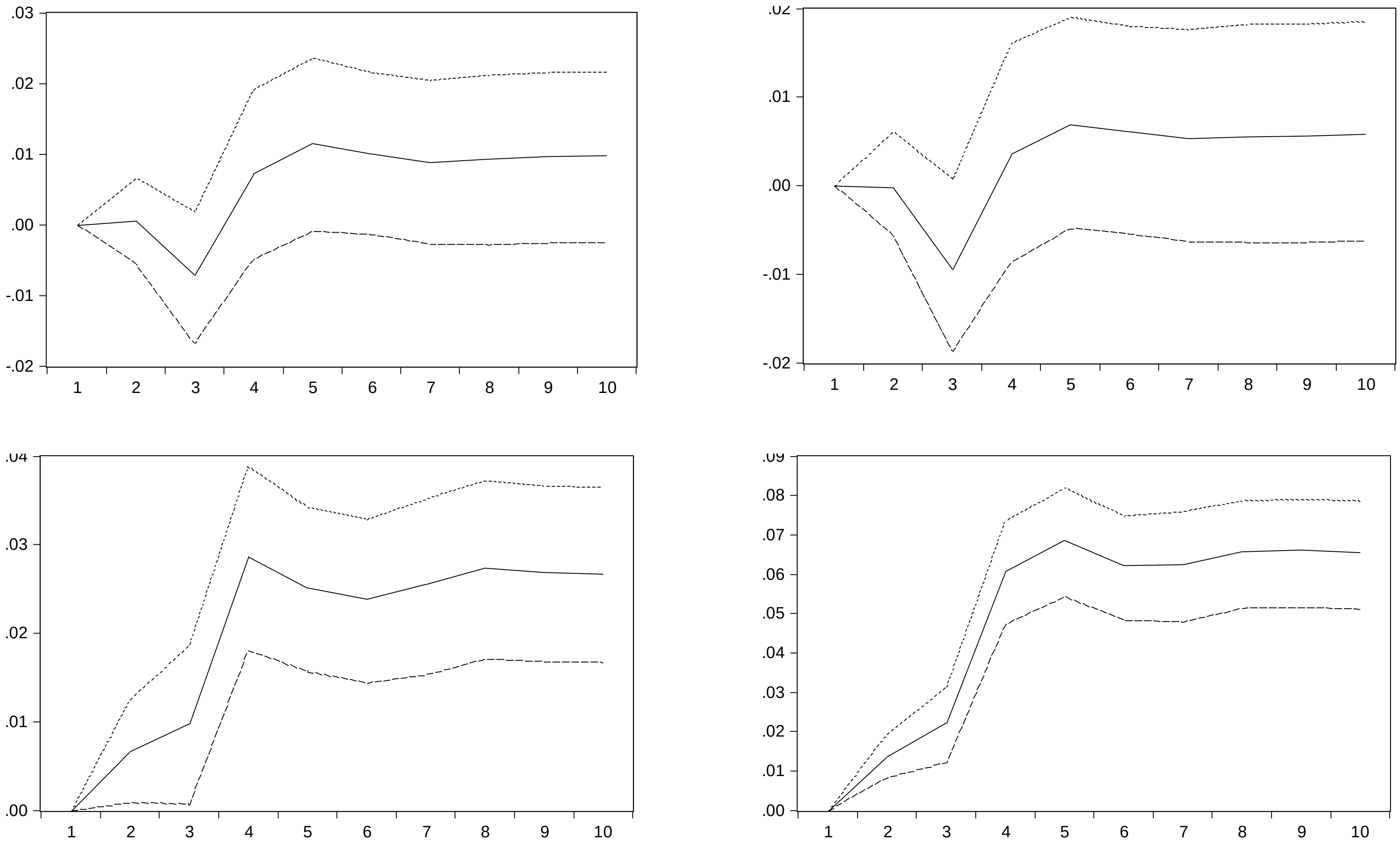


Appendix H *Granger causality tests for IRS in advanced economies.*

	6FL						3FL					
	2 lags		3lags		4lags		2 lags		3lags		4lags	
	p	obs	p	obs	p	obs	p	obs	p	obs	p	obs
1y	0.014**	1619	0.000***	1582	0.000***	1545	0.108	1416	0.000***	1380	0.001***	1344
2y	0.006***	1645	0.000***	1608	0.000***	1571	0.604	713	0.03**	695	0.004***	677
3y	0.004***	1645	0.000***	1608	0.000***	1571	0.459	713	0.016**	695	0.002***	677
4y	0.006***	1645	0.000***	1608	0.000***	1571	0.403	713	0.014**	695	0.002***	677
5y	0.008***	1645	0.000***	1608	0.000***	1571	0.399	713	0.016**	695	0.004***	677
6y	0.014**	1619	0.000***	1608	0.000***	1571	0.593	492	0.031**	478	0.008***	464
7y	0.017**	1645	0.000***	1608	0.000***	1571						
8y	0.023**	1619	0.000***	1582	0.000***	1545	0.679	492	0.028**	478	0.009***	464
9y	0.025**	1619	0.000***	1582	0.000***	1545	0.722	492	0.031**	478	0.014**	464
10y	0.026**	1645	0.000***	1608	0.000***	1571	0.683	713	0.019**	695	0.012**	677
12y	0.003***	1279	0.000***	1247	0.000***	1216	0.656	551	0.005***	537	0.003***	523
15y	0.003***	1282	0.000***	1250	0.003***	1282	0.892	571	0.023**	555	0.025**	539
20y	0.000***	1142	0.000***	1115	0.000***	1115	0.819	571	0.021**	555	0.019**	539
25y	0.018**	956	0.000***	934	0.000***	912						
30y	0.011**	900	0.000***	879	0.000***	858						

Note: The table lists p-values of Granger causality tests of the effect of the GPR index on the target variable. ** and *** denote tests that reject the null of no Granger causality with 95 and 99% confidence. Joint p-values of all 6 variables on IRS rate as the dependent variable are in each case equivalent to over 99,9% confidence.

Appendix I *Impulse responses for bonds with 30-year maturity and 3 lags in Western regional group. Global, USA, Chinese, and Russian GPR indexes displayed from left to right.*



Appendix J *3FL interest rate swaps with 2-year maturity from 1990 to 2022.*