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Analysis of Long-term Interest Rate Synchronization in Developed Countries

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Abstract

After the 2008 financial crisis, the co-movement of long-term interest rates in advanced countries has significantly increased, with a more noticeable rise following the COVID-19 pandemic. This thesis aims to identify the causes behind the synchronization of long-term interest rates in developed countries. To achieve this, I established a dynamic panel model for the determinants of long-term interest rates, followed by a panel analysis. This analysis revealed that inflation and short-term interest rates are significant determinants of long-term interest rates. Furthermore, a 3 dimensional vector autoregressive model was applied to each country individually to determine the dynamic effects, treating long-term interest rates, short-term interest rates, and inflation as endogenous variables, and the US long-term interest rates and inflation as exogenous variables. The findings indicate that US inflation significantly influences inflation in other countries, indirectly affecting the synchronization of long-term interest rates in developed nations. This suggests that central banks of each countries worldwide should place greater emphasis on monitoring US inflation shocks as a critical factor for managing interest rates.

Abstract

Nach der Finanzkrise von 2008 hat die Ko-Bewegung der langfristigen Zinssätze in den Industrieländern deutlich zugenommen, wobei ein noch stärkerer Anstieg nach der COVID-19-Pandemie zu beobachten war. Ziel dieser Arbeit ist es, die Ursachen für die Synchronisierung der langfristigen Zinssätze in Industrieländern zu identifizieren. Zu diesem Zweck wurde ein dynamisches Panel-Modell für die Determinanten langfristiger Zinssätze entwickelt, gefolgt von einer Panel-Analyse. Die Analyse zeigt, dass Inflation und kurzfristige Zinssätze wichtige Determinanten der langfristigen Zinssätze darstellen. Darüber hinaus wurde ein dreidimensionales Vektor-Autoregressionsmodell auf ausgewählte Länder angewendet, um die dynamischen Effekte zu untersuchen. Dabei wurden die langfristigen Zinssätze, die kurzfristigen Zinssätze und die Inflation als endogene Variablen betrachtet, während die langfristigen Zinssätze und die Inflation in den USA als exogene Variablen behandelt wurden. Die Ergebnisse deuten darauf hin, dass die US-Inflation die Inflation in anderen Ländern signifikant beeinflusst und indirekt zur Synchronisierung der langfristigen Zinssätze in Industrieländern beiträgt. Dies legt nahe, dass die Zentralbanken der einzelnen Länder der Überwachung von Inflationsschocks in den USA eine kritische Bedeutung für die Steuerung der Zinssätze beimessen sollten.

Contents

1 Introduction

In recent years, the phenomenon of increased synchronization of long-term government bond interest rates among several developed nations has garnered significant attention. This trend, particularly notable since the 2008 financial crisis, has important implications for the understanding of long-term interest rate co-movements. Such synchronization, occurring even among countries with differences in potential growth rates and national debt levels, poses significant challenges to individual monetary policies. This paper seeks to explore the causes of this increased alignment in long-term government bond interest rates, especially in the context of the post-2020 coronavirus pandemic - an era where prior research is somewhat limited.

This study builds upon the existing literature by incorporating post-pandemic data and applying a refined version of the models previously used by researchers in this field. Notably, a new pattern has been observed where countries, which traditionally did not exhibit synchronized financial behaviors, are now showing a tendency towards harmonization in their long-term bond interest rates. This analysis aims to provide a deeper understanding of these evolving global financial dynamics and their implications.

Research in the field of interest rate synchronization primarily focuses on two aspects: the relationship between the United States and other countries, and the dynamics between developed and emerging economies. One notable study in the former category is by the Bank for International Settlements BIS(2015), which utilized a panel model to analyze the interplay between long-term and short-term interest rates in the United States and various small open economies. This study revealed that the monetary policies in most of these countries were aligned to prevent exchange rate appreciation and were in sync with the monetary policy of the U.S. Federal Reserve.

In the realm of developed-emerging country relationships, the International Monetary Fund IMF(2018) conducted a significant study. By applying principal component analysis to the dollar-denominated government bond yields of thirteen emerging countries, the IMF discovered a strong correlation between these yields and the long-term interest rates in the United States and the European Union.

Furthermore, the Bank of Korea(2018) extended this research by dissecting the long-term interest rates of major countries, including the United States, Germany, the United Kingdom, and Japan. Employing the methodology developed by Adrian,Crump,and Moench(2008), they used repeated linear regression analysis to break down these rates into components of short-term interest rate expectations and term premiums. Their analysis, comparing periods before and after the financial crisis, indicated a deepened synchronization of term premiums across these major countries since the onset of the crisis.

In this paper, i undertake a comprehensive examination of the correlation among long-term interest rates between different countries, with a particular emphasis on incorporating the most recent data from the post-coronavirus period. This analysis serves as a critical foundation for understanding the interconnectedness of global financial markets in the context of recent economic upheavals.

Building upon this correlation analysis, the study then progresses to estimate the determinants of these long-term interest rates. This is achieved through the application of a dynamic panel model, a sophisticated statistical tool that allows for a nuanced understanding of the factors influencing interest rates over time and across different countries.

After significant determinants have been identified, the study utilizes a Vector Autoregression with Exogenous Variables(VARX) model using these variables. This model is instrumental in analyzing the dynamic correlations, providing insights into how changes in one country's interest rates might impact others over time. By employing the VARX model, the paper aims to shed light on the temporal and causal relationships between the long-term interest rates of different countries, thereby offering a more comprehensive understanding of global financial dynamics.

2 Characteristics of Significant Co-movement of Long-term Interest Rates in Developed Countries

The primary focus of this analysis is to observe and compare the long-term interest rate trends in these countries and to examine the changes in the correlation between each country's rates across the defined periods. As illustrated in Figure 1, a general pattern can be observed in the long-term interest rates across most of the countries under study. Typically, these rates exhibit a declining trend, followed by a rise attributable to various economic shocks, and most notably, show a tendency for an increase in the aftermath of the COVID-19 pandemic. This pattern not only highlights the impact of global economic events on interest rates but also sets the stage for a deeper exploration of the interlinkages between these nations' financial systems in the context of global economic upheavals.

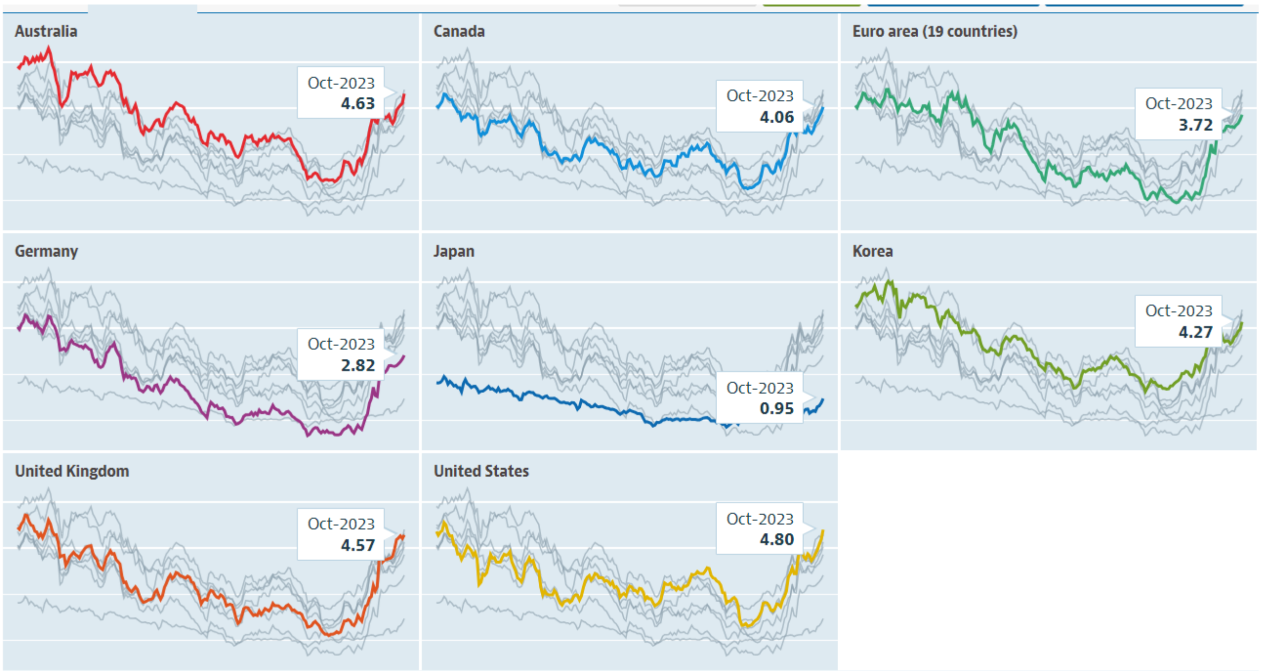

Figure 1: Movements of long-term interest rate from 2002 to 2023, OECD

Further analysis reveals significant insights into the co-movement phenomenon of long-term interest rates between the countries in question. This is particularly evident when examining the changes in the correlation coefficients of these interest rates, as depicted in Figure 2. Prior to the coronavirus pandemic, the data indicates that the correlation between the long-term interest rates of these countries was generally weak, and in some cases, even a negative correlation was observed.

However, a marked shift is noticeable following the financial crisis. During this period, the correlation coefficients increased substantially, indicating a stronger and more pronounced co-movement among these nations' interest rates. Most notably, in the post-coronavirus era, the correlation reached significantly higher levels. This trend suggests a heightened level of synchronization in the long-term interest rates of these countries, particularly in the wake of major global economic events such as the financial crisis and the coronavirus pandemic. The data from this period underscores the profound impact of these events on global financial markets, as reflected in the synchronized movements of long-term interest rates across diverse economies.

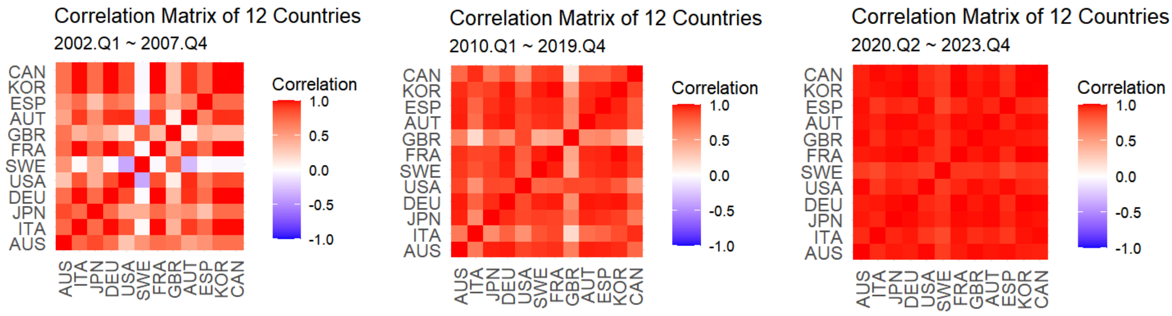

Figure 2: Correlation of Long-term interest rate, OECD

3 Dynamic Panel Analysis

To investigate the factors influencing long-term interest rates, a fixed effect panel model included lag variable is proposed as an effective analytical tool. In panel data analysis, the historical values of the dependent variable often hold significant importance due to the possibility of serial correlation. This serial correlation implies that past values of the dependent variable can significantly influence its current value. But in this case, inherent challenge in such scenarios is the potential endogeneity problem, it can arise not only from correlation between fixed effect by countries and explanatory variables but also from correlation between explanatory variables and the error term in case we include lagged dependent variable as explanatory variable.

Therefore, when using the normal least squares dummy method, there may be bias in the estimation coefficient. Nickell(1981) derived an equation representing the bias of the estimation coefficient and showed that this bias converges to 0 as the time of the panel data goes to infinity which means the longer the time series data included in the panel data, the more accurate result the normal least squares dummy variable method has. However, in any case, bias will inevitably occur in the limitedind finite time series data we have. To solve this problem, various estimators have been suggested that use instrumental variables. In this paper, i will estimate using the dynamic panel General Method of Moments(GMM) approach, as suggested by Arellano and Bover(1995).

Given the nature of long-term interest rates, where historical values can exert substantial influence on current rates, employing a dynamic panel model is particularly apt.

For the analysis, we consider the following specification, assuming the availability of only a limited set of variables. The model includes data from 11 selected developed countries over the period from 2002 to 2022, and also there are no missing values in the data, which means balanced panel. :

$$
\begin{aligned}
LR_{i,t} = \alpha_0 + \alpha_i + \beta_0 LR_{i,t-1} + \beta_1 \mathrm{GDP}_{i,t} + \beta_2 \mathrm{Inflation}_{i,t} + \beta_3 \mathrm{CA}_{i,t} + \beta_4 \mathrm{Debt}_{i,t} + \beta_5 \mathrm{SR}_{i,t} \\
+ \beta_6 \mathrm{EX}_{i,t} + \beta_7 \mathrm{VIX}_t + \varepsilon_{i,t} \qquad (1)
\end{aligned}
$$

Where:

- $LR_{i,t}$ is the long-term interest rate.
- $LR_{i,t-1}$ is the lagged value of the long-term interest rate, capturing past influences.
- $GDP_{i,t}$ is real growth rate.
- $Inflation_{i,t}$ is the inflation rate.
- $CA_{i,t}$ is the current account balance.
- $Debt_{i,t}$ is the government debt as a percentage of GDP.
- $SR_{i,t}$ is the short-term interest rate.
- $EX_{i,t}$ is the exchange rate to US dollar.
- VIX_t is the average annual Chicago board option exchange volatility index.
- $\epsilon_{i,t}$ is the error term.

In this model, α_i captures country-specific effects, while α_0 is the intercept. The coefficients β_0 to β_6 measure the impact of each independent variable on the long-term interest rate.

Following is the result of estimation about long-term interest rate using dynamic system GMM.

The results of the dynamic panel analysis reveal some interesting insights into the factors influencing long-term interest rates. Table 1 shows the result of estimation. Specifically, the growth rates and current account balances do not appear to have a significant impact on long-term interest rates. However, the one-period lagged value of long-term interest rates, along with the inflation rate and short-term interest rates, demonstrate a very significant influence on long-term interest rates.

Table 2 shows the model diagnostics.

The Sargan test, used for assessing overidentifying restrictions in the model, yields a high p-value. This suggests that over-identify restrictions of our model are valid.

The AR(1) test checks for first-order autocorrelation, and according to Arellano(1991), finding significant autocorrelation (a very low p-value, suggesting to reject the null hypothesis of no first-order autocorrelation) is expected in differenced models, as it reflects the transformation's effect on the data structure. This outcome does not invalidate the model but rather aligns with the anticipated behavior of the differencing process.

Conversely, the AR(2) test assesses second-order autocorrelation. Failing to reject the null hypothesis here (indicating no second-order autocorrelation with a p-value around or above 0.05) suggests that the differencing has effectively addressed serial correlation. This result is important for the model's validity.

Thus, we reject the null hypothesis for AR(1) and fail to reject the null hypothesis for AR(2), confirming that our model is not misspecified.

The Wald tests, which assess the joint significance of the coefficients and time dummies, show very low p-values. This indicates that both the coefficients and the time dummies in our model are highly significant, adding robustness to the findings.

Indeed, an interesting pattern emerges when examining the correlation between these countries' inflation rates and short-term interest rates, particularly when focusing on the periods before and after the financial crisis, as well as the post-pandemic era. This trend is further elucidated through the analysis of the following correlation matrix. The matrix provides a detailed view of how these variables are interrelated across different countries and time periods, highlighting a strengthened correlation in these specific intervals. Although it only shows static correlation, it can be meaningful to see this change of correlation between countries, because it can imply some important change of financial situation in the world.

Table 1: Dynamic Panel GMM Estimation Results

Variable	Estimate	Std. Error	z-value	p-value
lag(LR, 1)	0.76933975	0.02404380	31.9974	$< 2.2e-16$***
Growth	0.01383419	0.01567995	0.8823	0.37762
CA	-0.00432019	0.00622617	-0.6939	0.48776
Inflation	0.18611084	0.03311598	5.6200	1.910e-08 ***
Dept	0.00126690	0.00056705	2.2342	0.02547 *
SR	0.15804660	0.02312421	6.8347	8.219e-12 ***
EX	-0.18331286	0.07236123	-2.5333	0.01130 *
VIX	-0.00198075	0.00355055	-0.5579	0.57693

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 2: Model Diagnostics

Test	Statistic (p-value)
Sargan test	chisq(209) = 11 (p-value = 1)
Autocorrelation test (1)	normal = -2.936873 (p-value = 0.0033154)
Autocorrelation test (2)	normal = -1.958816 (p-value = 0.050134)
Wald test for coefficients	chisq(8) = 862358.4 (p-value = $< 2.22e-16$)

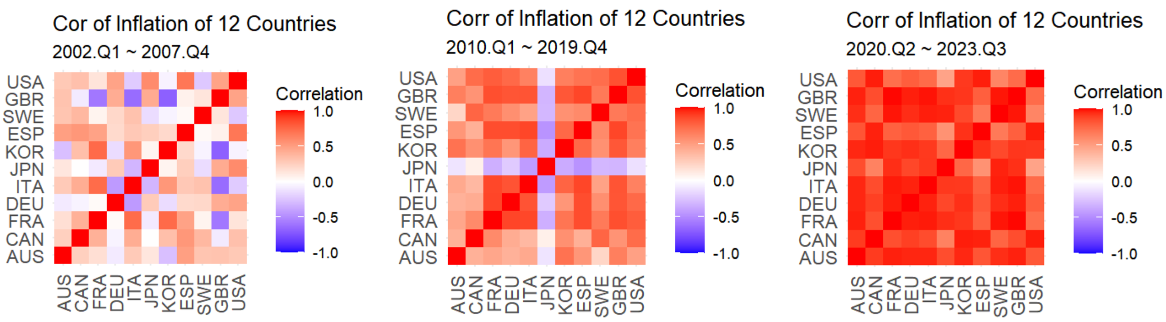

Figure 3: Correlation of Inflation rate, OECD

4 VAR Analysis by Individual Country

In this section, we delve into an analysis using Vector Autoregression with Exogenous Variables (VARX) to explore the dynamic correlations between significant variables and long-term interest rates within individual countries. The VARX model structure is particularly well-suited for assessing dynamic interactions and feedback mechanisms among endogenous variables, while also incorporating exogenous variables. This model captures the relationships of a set of endogenous variables with their own lagged values and exogenous variables, thus allowing us to analyze temporal dynamics and interdependencies.

The general form of our VARX(p) model is specified as follows:

$$Y_t = \mathbf{A}_0 + \sum_{i=1}^{p} \mathbf{A}_i Y_{t-i} + \sum_{j=0}^{q} \mathbf{B}_j X_{t-j} + \varepsilon_t \tag{2}$$

In our case , Where:

- Y_t is an 3×1 vector of endogenous variables(each country's variables) at time t,
- X_t is an 3×1 vector of exogenous variables(US variables) at time t,
- $\mathbf{A}_0$ is an 3×1 vector of intercepts,
- $\mathbf{A}_i$ for $i = 1, \ldots, p$ are 3×3 matrices of coefficients for the ith lag of endogenous variables,
- $\mathbf{B}_j$ for $j = 0, \ldots, q$ are 3×3 matrices of coefficients for the jth lag of exogenous variables (with $j = 0$ representing the current period),
- ε_t is an 3×1 vector of error terms at time t.

The data was analyzed as quarterly data collected from the second quarter of 2002 to the third quarter of 2023 and United States, Korea, Germany, Japan, Australia, United Kindom, Canada and Sweden are analyzed in this paper.

Prior to estimating the Vector Autoregression(VAR) model, it is very important to first ensure the stationarity of all variables involved. Stationarity is a fundamental prerequisite in time series analysis, particularly for VAR models, as it ensures that the properties of the time series do not change over time. Non-stationary data can lead to spurious results in VAR analysis. To address this,the KPSS(Kwiatkowski-Phillips-Schmidt-Shin) test can be considered as a stationarity test. This step is essential to validate the appropriateness of the VAR model for our analysis and to ensure the reliability of the subsequent findings.

Table 3 shows the result of stationarity test.

After applying the first difference, the results indicate that all variables, across all countries, exhibit evidence of stationarity.

To determine the lag order, the Schwarz Criterion (SC) is utilized as the information criterion in our model. According to the SC, a lag order of 1 is preferred for all the countries analyzed. The following section presents the estimation results of the VARX(1) model between the USA and each of the countries.

Table 3: Result of Stationarity Tests(KPSS) after first Differencing

Country	Variable	p-value	Conclusion
USA	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	over 0.1	Stationary
Korea	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	0.07196	Stationary
Germany	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	over 0.1	Stationary
Japan	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	over 0.1	Stationary
Australia	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	over 0.1	Stationary
UK	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	0.08127	Stationary
Canada	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	0.06625	Stationary
Sweden	dInflation	over 0.1	Stationary
	dSR	over 0.1	Stationary
	dLR	0.07152	Stationary

5 Result of Estimation VARX(1)

The VARX(1) model results indicate that inflation in the United State significantly influences the inflation rates of other countries contemporaneous and also with lag indirectly. This relationship suggests that inflation rates in the United States have the potential to affect the synchronization of long-term interest rates across different countries. Therefore, fluctuations in US inflation, triggered by any form of economic shock, could serve as a critical factor for the synchronization of long-term interest rates among these nations. This finding underscores the importance of monitoring changes in US inflation as a predictive indicator for global long-term interest rate trends. It is also very notable that by long-term interest rate causes short-term interest rate, which indicates that it can be also effect of US inflation.

Table 4: VAR Estimation Results for USA only

Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
		IF.usa		
IF.usa.l1	0.25221	0.10973	2.299	0.0241*
SR.usa.l1	-0.52312	0.23737	-2.204	0.0304*
LR.usa.l1	0.31060	0.31536	0.985	0.3276
const	0.04094	0.09841	0.416	0.6785
		SR.usa		
IF.usa.l1	0.03022	0.04430	0.682	0.4971
SR.usa.l1	0.46664	0.09585	4.869	5.56e-06***
LR.usa.l1	0.32988	0.12734	2.591	0.0114*
const	0.03027	0.03973	0.762	0.4484
		LR.usa		
IF.usa.l1	-0.038456	0.042927	-0.896	0.3730
SR.usa.l1	-0.051764	0.092866	-0.557	0.5788
LR.usa.l1	0.264076	0.123376	2.140	0.0354*
const	0.006687	0.038499	0.174	0.8625

Table 5: VARX Estimation Results between Korea and USA

VARX Estimation Results

Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
		Equation IF.kor		
IF.kor.l1	0.08288	0.08971	0.924	0.358
SR.kor.l1	0.21662	0.15351	1.411	0.162
LR.kor.l1	0.09143	0.17895	0.511	0.611
const	0.01228	0.05159	0.238	0.813
IF.usa	0.38302	0.05801	6.603	4.65e-09***
SR.usa	-0.15749	0.13451	-1.171	0.245
LR.usa	0.25239	0.17965	1.405	0.164
		Equation SR.kor		
IF.kor.l1	0.10052	0.05421	1.854	0.0676.
SR.kor.l1	0.03260	0.09277	0.351	0.7263
LR.kor.l1	0.23025	0.10815	2.129	0.0364*
const	-0.02470	0.03118	-0.792	0.4306
IF.usa	0.07564	0.03506	2.158	0.0341*
SR.usa	0.44826	0.08129	5.514	4.5e-07***
LR.usa	0.02292	0.10857	0.211	0.8334
		Equation LR.kor		
IF.kor.l1	-0.04930	0.04496	-1.096	0.27630
SR.kor.l1	-0.08062	0.07694	-1.048	0.29803
LR.kor.l1	0.23900	0.08969	2.665	0.00938**
const	-0.01962	0.02586	-0.759	0.45033
IF.usa	0.03514	0.02908	1.209	0.23050
SR.usa	-0.01418	0.06742	-0.210	0.83402
LR.usa	0.52658	0.09005	5.848	1.14e-07***
Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

Table 6: VARX Estimation Results between Germany and USA

VARX Estimation Results				
Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
Equation IF.ger				
IF.ger.l1	0.272924	0.097273	2.806	0.00635**
SR.ger.l1	-0.002106	0.162539	-0.013	0.98969
LR.ger.l1	-0.257191	0.219607	-1.171	0.24515
const	0.011133	0.053037	0.210	0.83429
IF.usa	0.290103	0.059387	4.885	5.5e-06***
SR.usa	0.216780	0.147037	1.474	0.14447
LR.usa	0.381776	0.181019	2.109	0.03819*
Equation SR.ger				
IF.ger.l1	0.063738	0.046619	1.367	0.175534
SR.ger.l1	0.475036	0.077898	6.098	4e-08***
LR.ger.l1	0.199409	0.105248	1.895	0.061891.
const	-0.004147	0.025418	-0.163	0.870839
IF.usa	0.013208	0.028462	0.464	0.643910
SR.usa	0.275379	0.070468	3.908	0.000199***
LR.usa	0.088689	0.086754	1.022	0.309840
Equation LR.ger				
IF.ger.l1	0.07235	0.02990	2.420	0.01788*
SR.ger.l1	0.13187	0.04995	2.640	0.01004*
LR.ger.l1	0.12772	0.06749	1.892	0.06220.
const	-0.01786	0.01630	-1.096	0.27667
IF.usa	-0.01189	0.01825	-0.652	0.51664
SR.usa	-0.12821	0.04519	-2.837	0.00582**
LR.usa	0.75334	0.05563	13.541	$< 2e-16$***
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Table 7: VARX Estimation Results between Italy and USA

VARX Estimation Results				
Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
Equation IF.ita				
IF.ita.l1	0.3088737	0.1130392	2.732	0.007793**
SR.ita.l1	-0.3138208	0.2170707	-1.446	0.152317
LR.ita.l1	0.1096682	0.2024415	0.542	0.589570
const	0.0008779	0.0718500	0.012	0.990283
IF.usa	0.2963643	0.0810287	3.658	0.000464***
SR.usa	0.2872090	0.2016411	1.424	0.158383
LR.usa	0.1632134	0.2455106	0.665	0.508170
Equation SR.ita				
IF.ita.l1	0.011443	0.041339	0.277	0.783
SR.ita.l1	0.540416	0.079385	6.808	1.92e-09***
LR.ita.l1	-0.006281	0.074035	-0.085	0.933
const	-0.009907	0.026276	-0.377	0.707
IF.usa	0.022726	0.029633	0.767	0.445
SR.usa	0.327511	0.073742	4.441	2.95e-05***
LR.usa	0.088106	0.089786	0.981	0.330
Equation LR.ita				
IF.ita.l1	0.100670	0.063451	1.587	0.116702
SR.ita.l1	0.143681	0.121845	1.179	0.241946
LR.ita.l1	0.200393	0.113633	1.764	0.081782.
const	-0.005864	0.040330	-0.145	0.884769
IF.usa	0.002276	0.045483	0.050	0.960225
SR.usa	-0.077160	0.113184	-0.682	0.497462
LR.usa	0.512183	0.137809	3.717	0.000381***
Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

Table 8: VARX Estimation Results between Japan and USA

VARX Estimation Results				
Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
Equation IF.jpn				
IF.jpn.l1	0.09756	0.10864	0.898	0.37201
SR.jpn.l1	1.59489	1.47834	1.079	0.28403
LR.jpn.l1	0.17027	0.47179	0.361	0.71915
const	0.03175	0.06251	0.508	0.61299
IF.usa	0.21595	0.06969	3.098	0.00272**
SR.usa	0.21660	0.15995	1.354	0.17965
LR.usa	0.02631	0.20982	0.125	0.90054
Equation SR.jpn				
IF.jpn.l1	0.0005513	0.0056993	0.097	0.9232
SR.jpn.l1	0.6568065	0.0775510	8.469	1.27e-12***
LR.jpn.l1	0.0464618	0.0247490	1.877	0.0643.
const	-0.0005927	0.0032791	-0.181	0.8570
IF.usa	0.0030323	0.0036561	0.829	0.4094
SR.usa	0.0210920	0.0083908	2.514	0.0140*
LR.usa	0.0091390	0.0110068	0.830	0.4089
Equation LR.jpn				
IF.jpn.l1	-0.010947	0.021912	-0.500	0.619
SR.jpn.l1	0.081568	0.298166	0.274	0.785
LR.jpn.l1	-0.014211	0.095154	-0.149	0.882
const	-0.003343	0.012607	-0.265	0.792
IF.usa	-0.015953	0.014057	-1.135	0.260
SR.usa	-0.048318	0.032261	-1.498	0.138
LR.usa	0.278883	0.042319	6.590	4.91e-09***
Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

Table 9: VARX Estimation Results between Australia and USA

VARX Estimation Results				
Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
Equation IF.aus				
IF.aus.l1	0.04545	0.08530	0.533	0.596
SR.aus.l1	-0.02985	0.16702	-0.179	0.859
LR.aus.l1	0.31947	0.18486	1.728	0.088.
const	0.01542	0.05516	0.280	0.780
IF.usa	0.48487	0.06246	7.763	2.91e-11***
SR.usa	0.16490	0.15737	1.048	0.298
LR.usa	0.15501	0.18415	0.842	0.403
Equation SR.aus				
IF.aus.l1	-0.0347082	0.0510983	-0.679	0.499
SR.aus.l1	0.4234060	0.1000471	4.232	6.33e-05***
LR.aus.l1	0.3079077	0.1107311	2.781	0.00682**
const	-0.0002861	0.0330396	-0.009	0.993
IF.usa	0.1112141	0.0374136	2.973	0.00394**
SR.usa	0.0972553	0.0942631	1.032	0.305
LR.usa	0.1728555	0.1103068	1.567	0.121
Equation LR.aus				
IF.aus.l1	-0.001686	0.032586	-0.052	0.958877
SR.aus.l1	0.030520	0.063801	0.478	0.633748
LR.aus.l1	0.159179	0.070615	2.254	0.027027*
const	-0.002588	0.021070	-0.123	0.902546
IF.usa	0.028469	0.023859	1.193	0.236451
SR.usa	-0.222846	0.060113	-3.707	0.000393***
LR.usa	0.912977	0.070344	12.979	$< 2e-16$***
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Table 10: VARX Estimation Results between UK and USA

VARX Estimation Results				
Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
Equation IF.uk				
IF.uk.l1	0.574030	0.076950	7.460	1.11e-10***
SR.uk.l1	0.048292	0.122565	0.394	0.6947
LR.uk.l1	-0.181098	0.149338	-1.213	0.2290
const	0.004273	0.039314	0.109	0.9137
IF.usa	0.350296	0.043500	8.053	8.05e-12***
SR.usa	0.019638	0.120726	0.163	0.8712
LR.usa	0.233698	0.136408	1.713	0.0907.
Equation SR.uk				
IF.uk.l1	-0.0056243	0.0554581	-0.101	0.91948
SR.uk.l1	0.4604193	0.0883334	5.212	1.52e-06***
LR.uk.l1	0.0905872	0.1076283	0.842	0.40258
const	0.0004204	0.0283339	0.015	0.98820
IF.usa	0.0405368	0.0313509	1.293	0.19988
SR.usa	0.3471438	0.0870079	3.990	0.00015***
LR.usa	0.1903496	0.0983101	1.936	0.05651.
Equation LR.uk				
IF.uk.l1	3.720e-02	3.525e-02	1.055	0.2945
SR.uk.l1	1.536e-01	5.614e-02	2.737	0.0077**
LR.uk.l1	8.865e-02	6.840e-02	1.296	0.1989
const	3.467e-05	1.801e-02	0.002	0.9985
IF.usa	-1.675e-02	1.993e-02	-0.841	0.4031
SR.usa	-1.066e-01	5.530e-02	-1.928	0.0576.
LR.usa	8.401e-01	6.248e-02	13.445	$< 2e-16$***
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Table 11: VARX Estimation Results between Canada and USA

VARX Estimation Results				
Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
Equation IF.can				
IF.can.l1	0.171217	0.069327	2.470	0.0157*
SR.can.l1	-0.053249	0.142656	-0.373	0.7100
LR.can.l1	-0.191332	0.188116	-1.017	0.3123
const	-0.008435	0.045993	-0.183	0.8550
IF.usa	0.595199	0.053408	11.144	2e-16***
SR.usa	0.062373	0.135631	0.460	0.6469
LR.usa	0.300427	0.155783	1.928	0.0575.
Equation SR.can				
IF.can.l1	0.056915	0.030046	1.894	0.06194.
SR.can.l1	0.182277	0.061826	2.948	0.00423**
LR.can.l1	0.053529	0.081527	0.657	0.51341
const	-0.006516	0.019933	-0.327	0.74465
IF.usa	0.050273	0.023146	2.172	0.03294*
SR.usa	0.643447	0.058781	10.947	2e-16***
LR.usa	0.010205	0.067515	0.151	0.88025
Equation LR.can				
IF.can.l1	0.030396	0.022674	1.341	0.184
SR.can.l1	-0.043515	0.046657	-0.933	0.354
LR.can.l1	0.060404	0.061526	0.982	0.329
const	-0.013581	0.015043	-0.903	0.369
IF.usa	0.009692	0.017468	0.555	0.581
SR.usa	-0.020171	0.044360	-0.455	0.651
LR.usa	0.730157	0.050951	14.331	$< 2e-16$***
Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

Table 12: VARX Estimation Results between Sweden and USA

VARX Estimation Results				
Equation	**Estimate**	**Std. Error**	**t-value**	**p-value**
Equation IF.swe				
IF.swe.l1	0.526224	0.095229	5.526	4.29e-07***
SR.swe.l1	-0.003754	0.173417	-0.022	0.9828
LR.swe.l1	-0.095595	0.208043	-0.459	0.6472
const	0.002428	0.058443	0.042	0.9670
IF.usa	0.379810	0.064335	5.904	9.04e-08***
SR.usa	0.151397	0.164009	0.923	0.3588
LR.usa	0.422576	0.198248	2.132	0.0362*
Equation SR.swe				
IF.swe.l1	0.062981	0.050543	1.246	0.21651
SR.swe.l1	0.408436	0.092041	4.438	2.99e-05***
LR.swe.l1	0.321253	0.110418	2.909	0.00473**
const	-0.002216	0.031019	-0.071	0.94324
IF.usa	0.064396	0.034145	1.886	0.06308.
SR.usa	0.139308	0.087047	1.600	0.11361
LR.usa	0.062372	0.105220	0.593	0.55506
Equation LR.swe				
IF.swe.l1	0.023570	0.033972	0.694	0.48989
SR.swe.l1	0.054507	0.061865	0.881	0.38102
LR.swe.l1	0.153495	0.074218	2.068	0.04198*
const	-0.014935	0.020849	-0.716	0.47594
IF.usa	-0.006245	0.022951	-0.272	0.78627
SR.usa	-0.197880	0.058509	-3.382	0.00113**
LR.usa	0.793422	0.070723	11.219	$< 2e-16$***
Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				

6 Impulse Response Analysis

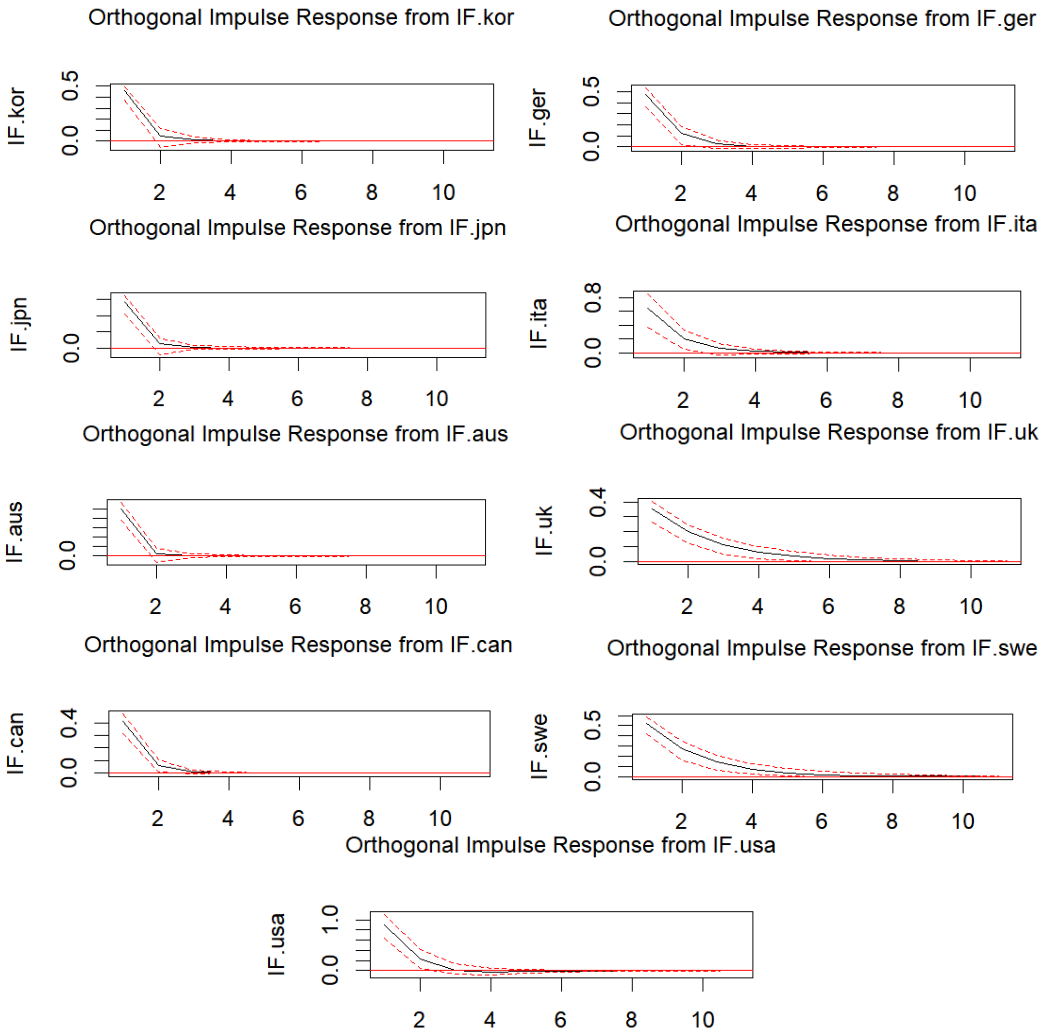

Figure 4: Impulse and response from own Inflation, 95% bootstrap CI

The concept of the impulse response function in a VARX(p) model is fundamentally the same as that in a VAR(p) model. The primary difference between VARX and VAR models lies in the absence of feedbacks into impulse from exogenous variables in VARX models. Therefore, the impulse response in a VARX model can be expressed using the Wold representation of a covariance-stationary VAR(p) model as following. It represent the mechanism through which shock spread over time. :

$$Y_j = C(L)\epsilon_t = \sum_{i=0}^{\infty} C_i \epsilon_{t-1} \tag{3}$$

The matrix $\mathbf{C}_j$ has the interpretation

$$\frac{\partial Y_t}{\partial \epsilon'_{t-j}} = C_j \tag{4}$$

or

$$\frac{\partial Y_{t+j}}{\partial \epsilon_t^{'}} = C_j \tag{5}$$

That is, the row i, column k element of $\mathbf{C}_j$ identifies the consequence of a unit increase in the kth variable's innovation at date t for the value of the ith variable at time t+j holding all other innovation at all day constant.

In this analysis, impulse response function for own inflation shock is examined, since there is no direct feedback into impulse from exogenous US variables. The result reveals that the impact of the own inflation shock persists for approximately two to four time periods, equivalent to from two to five quarters. Moreover, the magnitude of the response to this shock appears to be remarkably similar and consistent across the countries analyzed.

7 Inflation Shock in United States

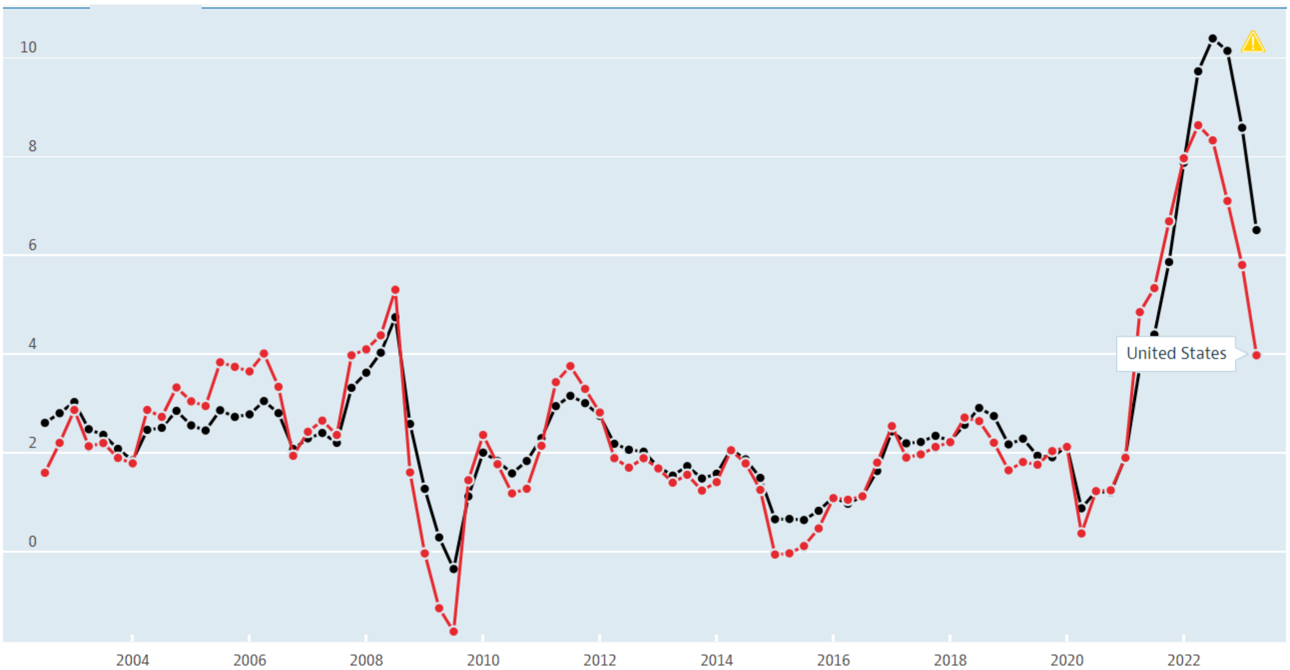

Figure 5: Change of Inflation rate in US from 2002 to 2023, OECD

Inflation has been confirmed as a significantly influential variable on long-term interest rates within each country's model for determining long-term interest rates, as established through dynamic panel model analysis. Additionally, the dynamic impact of each country's inflation on its own inflation rates was verified through a Vector Autoregression with Exogenous Variable

(VARX) model. Notably, the analysis revealed that the inflation in the United States is influential. This finding indicates that US inflation indirectly influences the long-term interest rates of these countries, thereby playing a pivotal role in the synchronization of long-term interest rates internationally. As we can see in figure 5, the inflation rate in the United States has fluctuated very significantly since the financial crisis began, and the inflation rate has fluctuated even more significantly since the coronavirus pandemic.

Specifically, the significance of inflation shocks in the United States extends beyond mere statistical correlation, as these shocks are intricately linked to global economic crises occurring within the same period. Such crises exert a profound impact on the policy-making decisions of individual countries, as well as on the investment choices of bond investors worldwide, particularly their propensity to purchase government bonds from developed nations. The interconnectedness of US inflation shocks with global economic dynamics necessitates a thorough consideration of their potential to influence international financial stability and policy formulation. Consequently, understanding the ripple effects of US inflation changes becomes paramount, especially in the context of its capacity to affect the global landscape of long-term interest rate syncronization and economic resilience.

8 Conclusion

In order to analyze the phenomenon of long-term interest rate synchronization in developed countries, which has become more pronounced after the financial crisis and the coronavirus pandemic, we established a dynamic panel model for the determinants of long-term interest rates. We estimated this model using the System GMM approach proposed by Arellano and Bover(1995), and identified significant variables influencing long-term interest rates. Subsequently, the dynamic relationship between these variables was examined using a VARX model that incorporated US macroeconomic variables. As a result, it was confirmed that inflation in the United States had a significant impact on the inflation in the other developed countries. This confirms that inflation shocks in the United States are not only an important indirect factor for synchronization of long-term interest rates in developed countries, but also important factor, that long-term interest rate causes short-term interest rate in these countries. Previous studies have indicated that changes in the term premium of government bonds in developed countries during this period, and factors significantly impacting bond investors' decisions to invest in government bonds, are related to this phenomenon as well. As the results of this study demonstrate, inflation shocks in the United States significantly influence the long-term interest rates of major countries. It is suggested that monitoring inflation in the United States is necessary to anticipate movements in long-term interest rates.

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