



Hacettepe University Graduate School of Social Sciences

Department of Economics

**YIELD CURVE SPILLOVERS AND MACROECONOMIC
INDICATORS: THE CASE OF TÜRKİYE**

Ünal KAYA

Ph.D. Dissertation

Ankara, 2025

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ACCEPTANCE AND APPROVAL

The jury finds that Ünal KAYA has on the date of 19/06/2025 successfully passed the defence examination and approves his Ph.D. titled “Yield Curve Spillovers and Macroeconomic Indicators: The Case of Türkiye”.

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ETİK BEYAN

Bu alıřmadaki bütn bilgi ve belgeleri akademik kurallar erevesinde elde ettiğimi, görsel, işitsel ve yazılı tüm bilgi ve sonuçları bilimsel ahlak kurallarına uygun olarak sunduğumu, kullandığım verilerde herhangi bir tahrifat yapmadığımı, yararlandığım kaynaklara bilimsel normlara uygun olarak atıfta bulunduğumu, tezimin kaynak gösterilen durumlar dışında özgün olduğunu, **Prof. Dr. Ayşen SİVRİKAYA** danışmanlığında tarafımdan üretildiğini ve Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Yazım Yönergesine göre yazıldığını beyan ederim.

Ünal KAYA

*I dedicate this thesis to my late grandfather,
Demir Ünsal, an idealist who graduated from Köy Enstitüleri.
It was a great pleasure for me to read the economic columns of newspapers to you!*

ACKNOWLEDGEMENTS

First and foremost, I would like to express my heartfelt gratitude to my family for their unwavering support under all circumstances: my parents, Sevin and the late Cengiz; my siblings, Melih Ünsal and İpek Nur; my elder brother's wife, Sinem; and their wonderful children—my nephew and niece—Çağatay and Ekin Günseli.

Lastly, I am profoundly thankful for the joy of having encountered so many remarkable individuals throughout my academic life. While I am unable to mention every name here, I sincerely appreciate all of them individually.

ABSTRACT

KAYA, Ünal. *Yield Curve Spillovers and Macroeconomic Indicators: The Case of Türkiye*, Ph.D. Dissertation, Ankara, 2025.

This study investigates the dynamics of Türkiye's yield curve and its interactions with domestic and foreign macroeconomic indicators between 2008 and 2021. Using data from 19 emerging market economies, including the U.S. and China, the research first estimates yield curve components—level, slope, and curvature—following the Diebold-Li (2006) framework. Then, employing a Global Vector Autoregression (GVAR) model with time-varying trade-weighted linkages, the study assesses how these components relate to macroeconomic variables. Generalized Impulse-Response Functions (GIRFs) and Orthogonalized Impulse-Response Functions (OIRFs) are used to interpret the direction and intensity of interactions.

Key findings reveal that Türkiye's yield curve is more influenced by domestic factors than external shocks. GIRF analysis shows a strong, bidirectional relationship between the level and slope components. Inflation is negatively associated with the slope, implying that higher inflation flattens or inverts the curve. The policy interest rate exhibits a weak but positive effect on the level. Notably, the domestic stock market significantly affects long-term rates, suggesting a link between investment sentiment and yield curve movements.

External influences are identified but found to be economically marginal overall. OIRF analysis, which is theoretically robust, provides weaker and less consistent results than GIRFs, especially regarding foreign impacts.

The study contributes to literature by offering a country-specific analysis of yield curve dynamics and monetary policy effectiveness in Türkiye. It suggests that monetary authorities can influence inflation via the policy rate through its transmission to yield curve components, though the robustness of this mechanism depends on the method used. Overall, the findings support the view that Türkiye's yield curve has been primarily shaped by domestic macroeconomic conditions rather than global integration during the period under study.

Keywords

Yield Curve, Diebold-Li method, Global Vector Autoregression

ÖZET

KAYA, Ünal. *Getiri Eğrisi Etkileşimleri ve Makroekonomik Göstergeler: Türkiye Örneği*, Doktora Tezi, Ankara, 2025.

Bu çalışma, 2008–2021 döneminde Türkiye’nin getiri eğrisi dinamiklerini ve bu eğrinin yurtiçi ile yurtdışı makroekonomik göstergelerle olan etkileşimini incelemektedir. Çalışmada, IMF tarafından gelişmekte olan ülke olarak sınıflandırılan 19 ülkenin verisi kullanılmış, ABD ve Çin’in etkileri de dahil edilmiştir. İlk aşamada Diebold ve Li (2006) yöntemiyle getiri eğrisi bileşenleri—seviye, eğim ve eğrilik—tahmin edilmiştir. İkinci aşamada, ikili ticaret ilişkilerine dayalı zamanla değişen ağırlıklarla oluşturulan Küresel Vektör Otoregresyon (GVAR) modeli yardımıyla bu bileşenlerin makroekonomik değişkenlerle olan ilişkisi analiz edilmiştir. Bulgular, Genel Etki-Tepki Fonksiyonları (GIRF) ve Ortogonal Etki-Tepki Fonksiyonları (OIRF) aracılığıyla yorumlanmıştır.

GIRF analizine göre Türkiye’nin getiri eğrisi bileşenlerinden seviye ve eğim arasında güçlü ve çift yönlü bir ilişki vardır. Enflasyonun eğim üzerindeki etkisi negatif olup, yüksek enflasyon eğrinin düzleşmesine ya da ters dönmesine neden olmaktadır. Politika faiz oranının seviye bileşeni üzerindeki etkisi zayıf ama pozitifdir. Ayrıca, hisse senedi piyasasındaki pozitif şokların uzun vadeli faiz oranlarını düşürdüğü bulunmuştur.

Yurtdışı etkiler gözlemlenmiş olsa da ekonomik anlamda sınırlı kalmıştır. Metodolojik olarak daha katı olan OIRF analizi GIRF’e kıyasla daha zayıf ve tutarsız sonuçlar sunmuştur.

Bu tez, Türkiye’ye özgü getiri eğrisi dinamiklerinin ve para politikası etkinliğinin anlaşılmasına katkıda bulunmakta; enflasyon hedeflemesi çerçevesinde, politika faizinin getiri eğrisi üzerinden enflasyon üzerinde dolaylı bir kontrol mekanizması olabileceğini göstermektedir.

Anahtar Sözcükler

Getiri Eğrisi, Diebold-Li Yöntemi, Küresel Vektör Otoregresyon

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ABBREVIATIONS

ADF	: Augmented Dickey Fuller	mal	: Malaysia
AIC	: Akaike Information Criterion	mex	: Mexico
AR	: Auto Regression	MSCI	: Morgan Stanley Capital International
AR GLS	: Auto Regression Generalised Least Squares	OLS	: Ordinary Least Squares
BIS	: Bank for International Settlements	pol	: Poland
bra	: Brazil	polra	: Policy Rate
bul	: Bulgaria	PP	: Phillips-Perron
chl	: Chile	rom	: Romania
chi	: China	rus	: Russia
col	: Colombia	safrica	: South Africa
curv	: Curvature	SBC	: Schwarz Bayesian Criterion
ERSPO	: Elliott Rothenberg Stock Point Optimal	skorea	: South Korea
excl.	: exclude	slp	: Slope
GDP	: Gross Domestic Product	Stock	: Stock Index Change
GFC	: Global Financial Crisis	s.d.	: standard deviation
GVAR	: Global Vector Auto Regression	thai	: Thailand
hun	: Hungary	tur	: Türkiye
HP-Filter	: Hodrick-Prescott Filter	TVAR	: Threshold Vector Auto Regression
IMF	: International Monetary Fund	US	: United States
IR	: Impulse-Response	USD	: United States Dollar
ind	: India	VAR	: Vector Auto Regression
indo	: Indonesia	VECM	: Vector Error Correction Model
indpro	: Industrial Production	vie	: Vietnam
infra	: Inflation Rate	WB GEM	: World Bank Global Economic Monitor
lvl	: Level	WITS	: World Integrated Trade Solutions

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INTRODUCTION

Interest rates are core components of economic decision-making, influencing every economic concept from personal savings behaviour to global capital flows. Understanding the structure of interest rates from short-term to long-term rates—or the yield curve—is essential for making informed predictions about the future direction of the economy, inflation, and financial markets. Policymakers, businesses, and individuals alike use interest rate information to guide their policy decisions, financial strategies, and economic forecasts.

A policymaker can affect numerous macroeconomic variables such as national output, unemployment and inflation through monetary policy, by altering the cost of borrowing, and fiscal policy, by issuing bonds. To understand the direction and strength of this effect, yield curves showing the yields of debt instruments with the same risk profile across different maturities can be examined (Kozicki and Tinsley, 2001). Yield curves not only provide insights about monetary and fiscal policies but also offer information about the future economic activities, inflation rates, or interest rate trajectories (Evans and Marshall, 2007). Therefore, many studies try to forecast yield curves and investigate their relationships with various macroeconomic variables such as inflation rates, economic growth, and interest rates (Estrella and Hardouvelis, 1991; Estrella and Mishkin, 1998; Stock and Watson, 2003). Prominent among these studies are Nelson and Siegel (1987) and Diebold and Li (2006), who decompose yield curves to latent factors. This approach facilitates obtaining components of yield curves as time series, thereby accounting for the role of expectations in determining bond yields across maturities.

However, increased integration among countries through labour mobility, trade, and capital flows can influence any country's domestic balances between yield curve and macroeconomic indicators as well. Dynamics that vary across countries, in any country, can alter economic entities' expectations and disrupt pricing behaviours. This situation may prevent the policy mix that is used by policymakers from producing effective results in the country. Therefore, investigating the relationships between yield curves and macroeconomic indicators requires a significant consideration of international interactions.

This study was motivated by the debates arising from the inability of monetary policies implemented in many countries, including Türkiye, to produce effective results in the post-Global Financial Crisis period. While monetary policy traditionally has the ability to influence the short end of the yield curve by adjusting short-term interest rates, the effectiveness of the policy on the yield curve can change under varying domestic and external conditions.

Based on this motivation, the research question is grounded on two main elements: domestic and foreign interactions. Before addressing the research question, it is important to define these interactions. Domestic interactions refer to the interaction between the yield curve, which is influenced by all types of monetary and fiscal policies implemented within a country, and macroeconomic indicators. Foreign interactions, on the other hand, can be defined as the extent to which a country's yield curve and macroeconomic indicators are influenced by the yield curves and macroeconomic indicators of other countries, through channels such as labour mobility, free trade, or capital flows, in line with increasing global integration. In this study, foreign interactions are examined using an extensive dataset that includes the United States (the U.S.) and China, the two largest economies in the world in terms of economic size. In a bipolar global conjuncture, the roles of these two countries play in global output are evaluated through bond markets and macroeconomic indicators. The primary research objective of the study is to investigate whether countries exert an external influence on Türkiye's yield curve through their respective yield curves and macroeconomic indicators. Furthermore, the study aims to understand the interaction between Türkiye's own yield curve dynamics and domestic macroeconomic indicators, and to identify both the direction and intensity of these interactions.

This study analyses countries classified as emerging economies by the IMF. The U.S. has been included in the analysis due to its significant influence on the global bond market and to observe external effects. Additionally, South Korea, which is still considered an emerging market by MSCI due to its use of stock indices in this study, has been added to the country set. A total of 19 countries' data has been used, covering the period from 2008 to 2021. The data begins in 2008 to reflect the post-Global Financial Crisis period. Furthermore, before 2008, there were no reliable bond market data available for many

emerging economies. The reason for the data ending in 2021 is to exclude, as much as possible, the effects of global lockdowns caused by the Covid-19 pandemic.

The thesis is structured around two-fold. In the first stage, using the dataset of 19 countries and following Diebold and Li (2006), the term structure of government bond yields denominated in local currency and traded with high liquidity is estimated by decomposing into its latent factors: level, slope and curvature. This decomposition is based on the yield rates across maturities of selected countries' sovereign bonds. Thus, these components for each country are obtained as time series. In the second stage, the Global Vector Auto Regression (GVAR) model is employed to examine the relationships between yield curve components and macroeconomic variables. Model establishes the connections (both in domestic and foreign factors) across countries by using bilateral trade relations. To impart a dynamic character to the model, the study employs time-varying weights of bilateral trade relations instead of fixed weights. Thus, the model will calibrate itself every year. To interpret the results better, the Generalized Impulse-Response Functions (GIRFs) are added to the analysis. GIRFs have been used to obtain the direction and intensity of the relationships between countries' yield curve and macroeconomic indicators. An additional OIRF analysis was conducted to support the GIRF findings.

The thesis contributes the literature in several ways. First, this thesis seeks to understand how yield curve dynamics function in Türkiye. Second, it aims to evaluate the effectiveness of monetary policy, represented by the policy rate that corresponds to the short end of the yield curve. In this context, the thesis intends to present findings on the extent to which the policy rate can influence the yield curve in the presence of external factors. Third and finally, the interaction between domestic macroeconomic indicators and the dynamics of the Turkish yield curve is examined. In this regard, the thesis also contributes to the development of the country-specific literature on the subject.

The structure of the thesis is as follows: Chapter 1 outlines the theoretical framework and the thesis's contribution to the literature. Chapter 2 reviews relevant studies on yield curves, macroeconomic variables, estimation methods, and global linkages. Chapter 3 describes the data, models, econometric methodologies, and computational implementation. Chapter 4 presents the empirical findings, and the final chapter offers conclusions and policy implications.

CHAPTER 1

THEORETICAL FRAMEWORK

The historical evolution of monetary policy and the significance of yield curves will be examined in this chapter. In doing so, the aim is to provide a foundational understanding of the origins and historical development of key definitions and concepts prior to the literature review. This background will also facilitate a clearer comprehension of the empirical analysis presented in the subsequent chapters of the thesis.

1.1. EVOLVING OF MONETARY POLICY

Economics is rooted in choice theory, focusing on decision-making at both individual and societal levels to allocate resources efficiently and maximize utility. Modern economics heavily revolves around human behaviour, employing mathematical, statistical, and machine learning methods to analyse data and detect changes in individual and organizational behaviour. Historically, economics as a science emerged during the Age of Enlightenment, when societal shifts from religious to reason-based thinking fuelled intellectual exploration. Pioneers like Adam Smith explained the foundations for capitalism in detail, while economists like David Ricardo and Karl Marx contributed to debates on wealth distribution and capitalism's flaws (Hunt and Lautzenheiser, 2011).

The Industrial Revolution increased productivity but also deepened class conflicts, prompting critiques from economists like Marx, who advocated for socialism. As economics evolved, its mathematical rigor grew, with figures like Stanley Jevons and Leon Walras formulizing concepts such as diminishing marginal utility. World War I and the Great Depression marked a significant shift, challenging classical economic theories like Say's Law¹ and leading to more government intervention. John M. Keynes emerged as a prominent figure, advocating for government policies to address economic instability, including the fixed money supply under the Bretton Woods system, which eventually collapsed (Truman, 2017).

¹ Jean Baptiste Say defends the “markets always find their equilibrium” claim.

The Bretton Woods system ended in the 1970s, following criticism from countries with significant reserves. These nations accused the U.S. of excessive public spending on military efforts and of monetizing its debts (Hammes and Wills, 2005). Monetizing the debts and increase in commodity prices caused a world-wide inflation in 70s. The modern focus on quantitative methods in economics grew while studying monetary policy in the 1970s and 1980s. During this time one of the main policy tools of the policy makers, interest rates were beginning to use in foundational models increasingly. Thus, the field of economics has evolved from verbal theories to complex mathematical frameworks, influenced by both societal needs and global events.

Milton Friedman, a key figure in monetarism, argued that high inflation was a result of Keynesian policies that do not prioritize but still care about the interest rates. In his work on the Quantity Theory of Money, he emphasized using real monetary aggregates to explain economic phenomena and stated that monetary policy should not be solely viewed as a tool for regulating employment or pegging interest rates (Friedman, 1968; Friedman, 1987). During this period, monetary policy focused on adaptive expectations, historical data analysis, managing the money supply, and adjusting the nominal interest rates. Meanwhile, advancements in econometrics led Robert Lucas to criticize traditional methods for being inflexible to changes in economic structures. Lucas's research, which explored the relationships between money supply, price inflation, and nominal interest rates, contributed to the theory of rational expectations and deepened understanding of monetary policy dynamics (Lucas, 1976; Lucas, 1980). The rational expectations hypothesis gained acceptance following Lucas' critique of adaptive expectations, marking the dominant paradigm in economics from the 1980s until the 2007-2008 Global Financial Crisis (GFC).

In the 1970s and 1980s, all approaches developed to curb high inflation strongly emphasized granting central banks full independence to set their goals and use policy tools. Friedman (2000) advocated for the establishment of rule-based frameworks in policymaking. However, rule-based economics has brought with itself, the need to guide society and highlighted the importance of communication. In order to distribute the effects of the set of rules evenly across society and minimize asymmetric information, forward guidance has been added to traditional tools (such as quantity of money and

interest rates). As monetary aggregates and interest rates began to operate with a very mechanical equation over time, the importance of forward guidance in the policies to be implemented has increased guiding economic expectations (Bernanke, 2015). As this historical background gains a mathematical dimension, it sheds light on the evolution of rule-based economic policy design grounded in measurable values within monetary economics. Moreover, the more recent addition of forward guidance demonstrates efforts to shape expectations. The role of expectations will become more meaningful in the section on the yield curve.

1.2. TERM STRUCTURE OF INTEREST RATES

1.2.1. Yield Curve as a Representation of the Term Structure

In the previous section, historical evolution of monetary policy has demonstrated the fundamental policy tools. Policy tools, such as quantitative settings, usage of interest rates, required reserves and forward guidance were shaped in time. Due to the increasing dominance of rule-based economics, these tools have been at the forefront of policy design for a long time. Nevertheless, the economy operates according to decision theory (Mas-Collel et al., 1995). Therefore, it is also necessary to examine the term structure of interest rates, which represents the cost of decisions in a meaning. Since the term structure of interest rates reflects the cost of interest included over the counter contracts in an economy at any given time, it contains information about the current state of the economy. For this reason, such an examination becomes important. Additionally, the examination allows for the measurement of the extent to which the designed policies affect the term structure of interest rates.

Practitioners often use the term *yield curve* to describe the term structure of interest rates. While the term structure of interest rates represents the theoretical background of interest rates and the maturities of related borrowing instruments, Mishkin (1990a) defines the yield curves as graphical representations showing the returns of bonds with the same risks but different maturities.

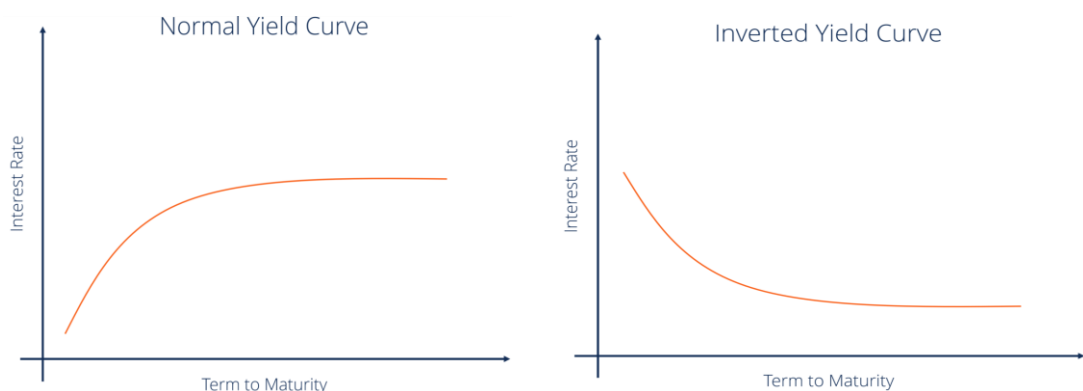
The seminal article, which carries substantial influence in term structure of interest rates, begins with the sentence:

"The need for a parsimonious model of the yield curve"

referred to Milton Friedman (Nelson and Siegel, 1987). The yield curve is an important indicator in macroeconomic analysis for monetary policy, borrowing, and treasury management. Its significance lies in the information it contains expectations about the economy. This is because the interest rates, classified according to their term structures and associated with all contracts made in the past and present, reflect the future state of the economy.

Some finance professionals classify the yield curves by looking its shape to provide an easily understandable concept (Choudry, 2019). According to these classifications, there are four types of yield curve: normal, inverted, flat, and humped.

1. Normal Yield Curve: is common shape of a yield curve. It has upward slope which means longer-term interest rates are higher than short-term rates.
2. Inverted Yield Curve: occurs when short-term interest rates are higher than long-term rates, causing the curve to slope downward. This can be a signal of economic uncertainty or a potential recession.
3. Flat Yield Curve: occurs when short-term and long-term interest rates are very close to each other. This indicate that the economy is in uncertainty about future activity. A flat yield curve may precede an economic slowdown or transition between different economic phases which reflects the different side of the cycles.
4. Humped Yield Curve: A humped yield curve shows interest rates that rise for a while and then decline, creating a "hump" in the middle. These shapes rare and can occur during periods of economic uncertainty or when markets expect short-term interest rates to rise and then decrease as economic conditions change.



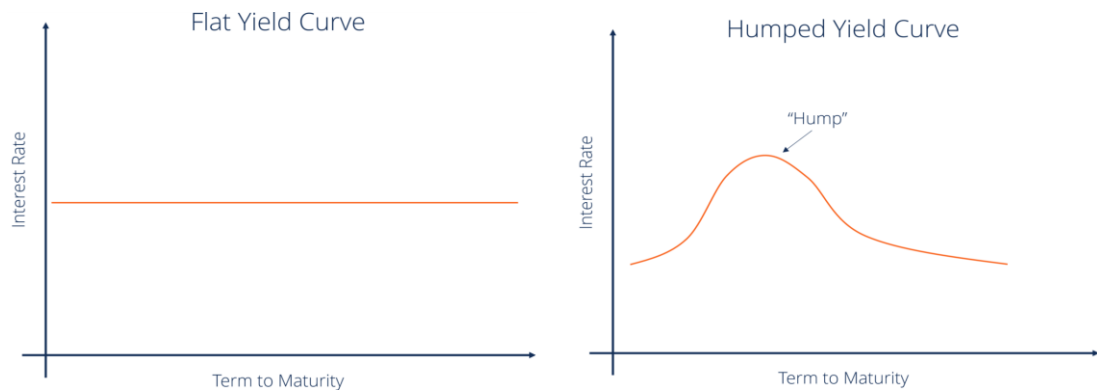


Figure 1. Types of the Yield Curves

Similarly, Nelson and Siegel (1987) classified the yield curves as monotonic, humped or *S* shaped which evaluates normal and inverted curves as monotonic, and humped type compounded curves as *S* shaped. Such classifications provide ease of verbal expression and visual clarity. In some uses, faster-rising versions of the normal yield curve are also called steepening or steep yield curves.

Normal and inverted yield curves are more natural formations in economic terms. However, flat and humped-shaped yield curves can be interpreted as undesirable outcomes in the economy. In an economic system where interest rates are set equally across all maturities (flat yield curve), it is impossible to make meaningful comments about the decisions of economic units, and it also indicates a lack of dynamism in the economy. Humped-shaped (or *S*-shaped) curves, on the other hand, often reflect interest rate variations resulting from market imperfections. Therefore, analysing the shape of yield curves to make comments about an economy will not always lead to the same conclusions. This statement is also valid especially when the global integration increases.

1.2.2. Hypotheses about the Term Structure

The theoretical background of the shapes in the yield curve also needs to be examined. While Cox et al. (1985) defines the term structure of interest rates as the measure of relationship among the yields that differ only in their term to maturity, they also argue the theories explaining the term structure. Through a comprehensive perspective, there are four strands of thought that define the term structure:

1. Expectations Hypothesis (EH): EH explains the relationship between short-term and long-term interest rates. Irving Fisher is considered a foundational figure in the

development of the Expectations Theory through his work on interest rates. In his book *The Theory of Interest* (1930), he emphasized that current interest rates are influenced by expectations of future economic conditions. Although he did not formally define the Expectations Theory of the term structure, his ideas laid the intellectual groundwork for later formalizations (Lutz, 1940). In his work, Lutz introduced the idea that long-term interest rates (R) are determined by the average of current and expected future short-term interest rates (r) over n periods. His formulation helped shaping modern interpretations of the term structure, building directly on earlier ideas by Irving Fisher and giving the theory a more rigorous, forward-looking foundation. In equation (1), the long-term average compound interest rate (R) is derived by averaging the compound short-term interest rates (r) over n future periods.

$$R_n = \frac{(1+r_1)(1+r_2)\dots(1+r_n)-1}{(1+r_2)(1+r_3)\dots(1+r_n)+(1+r_3)\dots(1+r_n)+\dots+(1+r_n)+1} \quad (1)$$

In modern versions of expectations hypothesis risk premiums are added into the equation. According to Cochrane and Piazzesi (2008), there are three strands of capturing yield curve relationships; (1) the long-term yield is average of expected future short-term rates plus a risk premium, (2) the forward rate is the expected future short rate plus a risk premium, and (3) the expected one period return on long-term bonds equals the expected return on short-term bonds plus a risk premium. In equations,

$$y_t^{(n)} = \frac{1}{n} E_t \left(y_t^{(1)} + y_{t+1}^{(1)} + \dots + y_{t+n-1}^{(1)} \right) + rpy_t^{(n)} \quad (2)$$

$$f_t^{(n)} = E_t \left(y_{t+n-1}^{(1)} \right) + rpf_t^{(n)} \quad (3)$$

$$E_t(r_{t+1}^{(n)}) = y_t^{(1)} + rpr_t^{(n)} \quad (4)$$

where y is bond yield, n is maturity, t is time, E is expectation operator, rp is risk premium, f is forward rate, r is one-period rate.

2. Liquidity Preference Hypothesis (LPH): LPH builds on the expectations hypothesis but emphasizes the role of risk preferences. It posits that risk aversion leads to forward rates being higher than expected spot rates, with the difference (term premium) increasing with maturity to compensate investors for holding riskier, long-term

securities. According to the definition of Cochrane and Piazzesi (2008), the yield curve risk premium (the difference between current yield and the average of expected future short rates) is the average of expected future return premia of declining maturity. Future term premia are expressed as rx in equation,

$$y_t^{(n)} - \frac{1}{n} E_t \left(y_t^{(1)} + y_{t+1}^{(1)} + \dots + y_{t+n-1}^{(1)} \right) = \frac{1}{n} \left[E_t \left(rx_{t+1}^{(n)} \right) + E_t \left(rx_{t+2}^{(n-1)} \right) + \dots + E_t \left(rx_{t+n-1}^{(2)} \right) \right] \quad (5)$$

In summary, short-term investors will be unwilling to hold long-term bonds unless the forward rate exceeds the expected short interest rate ($f > E(r)$), whereas investors will be unwilling to hold short-term bonds unless $E(r) > f$. In simpler terms, both groups of investors need an extra return to invest in bonds with maturities that don't match their investment timelines. Supporters of the liquidity preference theory of the term structure argue that short-term investors have more influence in the market, which causes the forward rate to usually be higher than the expected short-term rate. The excess of f over $E(r)$, liquidity premium is predicted to be positive.

To facilitate the understanding, Bodie et al. (2014) give the hypothesis in a simple example and illustrate the results. Assuming the short-term interest rate $r=5\%$ and $E(r)=5\%$ and under the expectations hypothesis, the 2-year yield to maturity (y) could be derived from $(1+y)^2 = (1+r) (1+E(r))$, which is y equals 5% like short rate (r) and the expected rate $E(r)$. In contrast, under the liquidity preference hypothesis, f would exceed $E(r)$. Hence, if the liquidity premium is 1% , then f will be equal to 6% ($E(r)+1\%$). Thus, the equation $(1+y)^2 = (1+r) (1+f)$ will yield y equals to $\sim 5.5\%$. Similarly, yield on 3-year bonds would be $\sim 5.7\%$ according to equation $(1+y)^3 = (1+r) (1+f_1) (1+f_2)$, and so on.

If interest rates are expected to change over time, the liquidity premium could be added to the expected spot rates to calculate the forward interest rate. As a result, the yield to maturity for each date will represent an average of the individual forward rates for each period. Results illustrated in Figure 2.

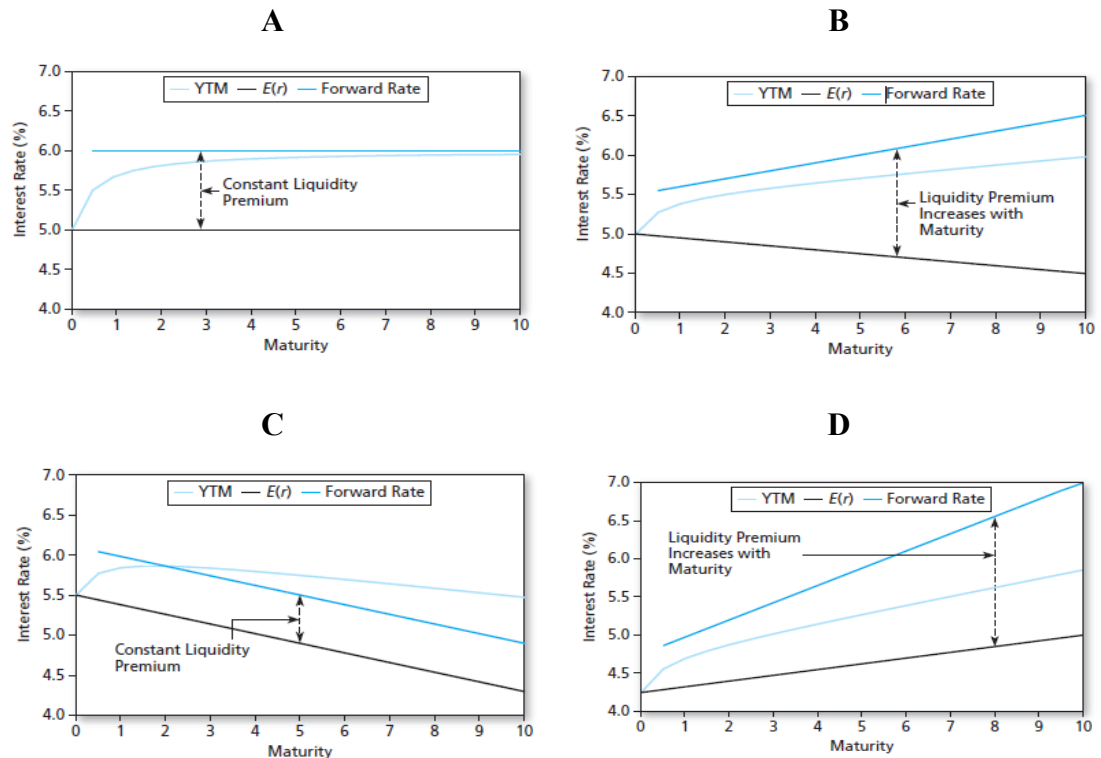


Figure 2. Liquidity Preferences on Yields

According to Panel A, together with constant expected short rate and liquidity premium of 1%, result is a rising yield curve. Panel B shows declining expected short rates with increasing liquidity premiums. Result is a rising yield curve despite falling expected interest rates. Panel C shows declining expected short rates with constant liquidity premiums. Result is a humped shape yield curve. Panel D shows increasing expected short rates with increasing liquidity premiums. Result is a sharply rising yield curve.

3. **Market Segmentation Hypothesis (MSH):** MSH argues that bonds of different maturities trade in distinct markets, with supply and demand for a particular maturity largely unaffected by neighbouring maturities (Kidwell and Koch, 1983). According to this theory, yields at each maturity are determined by the supply and demand within each segment, rather than the overall level of interest rates or expectations of future rates. For example, institutional investors like pension funds might prefer long-term bonds, while commercial banks might prefer shorter-term instruments.
4. **Preferred Habitat Theory (PHT):** PHT is an extension of the market segmentation and allows for some degree of arbitrage or substitution between segments. It recognizes

the limitations of market segmentation and offers a more flexible rationale. Essentially, investors may be willing to invest in bonds outside their preferred maturity range, but only if the yields in those segments are attractive enough to compensate for the risk or inconvenience of shifting away from their preferred maturity (Riedel, 2004).

This theoretical classification undoubtedly provides a comprehensive perspective on the term structure of interest rates and how the yield curves take their shape. While the expectations hypothesis provides a general framework for interest rates in shaping the yield curve, the liquidity preference hypothesis explains term premiums and investors' risk preferences. The market segmentation hypothesis suggests that bonds may be traded in separate and unrelated markets, whereas the preferred habitat theory accounts for investors' transitions across markets based on their perceptions and preferences.

In this thesis, the approach primarily focuses on sovereign bond markets of certain countries. Markets are assumed that only allows for differentiation in terms of maturity and interest rates. Hence, different taxations or risk premiums are not considered. In this context, when examining more general theoretical frameworks, it is understood that sovereign bond markets do not align with the market segmentation hypothesis based on market imperfections or the preferred habitat theory. On the other hand, because empirical part of the thesis assumes equal risk conditions for bonds with different maturities, the hypothesis of liquidity preference, where the risk premium increases as maturity extends, partially aligns with the approach (if the risk distributed equally and market is assumed liquid in all maturities). Moreover, dataset that are used in empirical part composed totally past data that reflect the realization of expectations. Thus, the empirical analysis based on ex-post evaluation. As a result, it is observed that the expectations hypothesis, which idealizes interest rates that differ according to expectations and allow for transitions between maturities, provides a theoretical foundation for this study.

1.3. CROSS-COUNTRY DYNAMICS AND THE YIELD CURVES

After discussing the Expectations Hypothesis, which seeks to explain the relationship between long- and short-term interest rates, and referencing Fisher, who establishes a connection in this context, it may also be useful to provide additional information by introducing the Fisher equation (equation 6) (Mishkin and Eakins, 2011). This connection may help to understand the remaining analysis in this study. The Fisher equation establishes a relationship between interest rates and inflation expectations.

$$i = r + \pi^e \quad (6)$$

where i is nominal interest rate, r is real interest rate and π^e is expected inflation rate. If two hypotheses are combined as summary: If investors expect higher inflation, the Fisher equation implies higher nominal short-term rates. These higher expected short-term rates, through the Expectations Hypothesis, would lead to higher long-term rates.

For the further understanding the relationship between inflation and interest rates, the Fisher Effect concept is required to be expressed as well. The Fisher Effect posits that when the expected inflation rate increases, the nominal interest rate will rise by the same amount, assuming the real interest rate remains constant (Mishkin and Eakins, 2011). This implies that monetary policy or inflation expectations directly influence nominal interest rates, but do not affect the real interest rate in the long run. An extended version of the Fisher Effect is the International Fisher Effect.

$$\frac{E(S_1) - S_0}{S_0} \approx i_{domestic} - i_{foreign} \quad (7)$$

where S_0 is the current spot exchange rate, $E(S_1)$ is the expected future spot exchange rate, $i_{domestic}$ and $i_{foreign}$ are the nominal interest rates in the domestic and foreign countries respectively. It suggests that differences in nominal interest rates between two countries are reflected in the expected changes in exchange rates between their currencies. Specifically, a country with a higher nominal interest rate is expected to experience a depreciation of its currency relative to a country with a lower interest rate (Koráb and Kapouněk, 2013). Increasing globalization, today, has brought this concept to the forefront. With a more global perspective, studies covering many countries have begun to be conducted on the inflation and the term structure of interest rates (Auer et al., 2024;

Gelleny and McCoy, 2001; Bae and Kim, 2011; Cavaca and Meurer, 2021). In light of the International Fisher Effect, analysing the economic dynamics among countries that reflect broader processes of globalization has gained increasing importance.

A strong commitment to a rule-based economy which expressed in previous sections triggered an acceleration in globalization until the Global Financial Crisis. In this period, decisions of economic agents became increasingly influenced not only by domestic policies but also by economic measures implemented in other countries. A recent study shows that global factors increase their impact on domestic inflation dynamics (Auer et al., 2024). In this study, inflation data from 56 countries spanning 1960 to 2023 have been analysed. Using common factor analysis, the inflation rates of the countries were decomposed into a shared inflationary factor affecting each other and a country-specific factor shaped by domestic dynamics. According to the study, global factors have a significant weight for explaining local inflation. As seen in inflation dynamics, globalization has profound impacts on economies at the macro level, primarily through increased labour mobility and trade expansion, then the facilitation of capital flows by a burgeoning financial sector. These developments pose growing challenges in evaluating the effectiveness of country-specific economic policies (Gelleny and McCoy, 2001).

Especially after periods of crises, the interest and criticism of global integration increase, leading to a rise in studies in globalization. In this context, Bae and Kim's (2011) study focuses on the interactions between the bond markets of 9 countries (the U.S., United Kingdom, Australia, Germany, France, South Korea, Japan, Singapore and Hong Kong) after the Asian crisis. The study examines the impact of global and local factors on the yield curves of four Asian countries. As a result, it was argued that while the impact of local factors was more limited, global factors had a more significant influence.

Under the existence of globalization, a significant research question emerges regarding whether monetary and fiscal policies could still achieve effective outcomes. Cavaca and Meurer (2021) searched the cross-country dynamics and considers linkages among yield curves between the U.S. and South American countries from 2006 to 2019. The results are significant as they reveal the presence and strength of international monetary spillovers, providing a foundation for calibrating models used in monetary policy, which are influenced by global shocks. Calibration requirement in policy making shows the

existence of external factors on Brazilian yield curve and proof the challenges that faced by making independent policy. In an open economy, when interest rates within the term structure are evaluated from a holistic perspective, they may be influenced by external factors, by internal dynamics that change according to maturity, or by domestic macroeconomic shocks. Research findings about external conditions on domestic inflation dynamics, and recalibration requirement for monetary policy highlight the need for a study that examines the relationship between yield curves and macroeconomic indicators, incorporating external conditions as well. The detailed literature review in the following section further explores the research question.

CHAPTER 2

LITERATURE REVIEW

The theoretical framework chapter aimed to explain key concepts, their historical evolution, interest rates as a policy tool, term structures derived from interest rates, and the main theories that explain the term structure of interest rates. Additionally, this chapter provided insights into the shapes of yield curves and how they should be interpreted. In order to maintain alignment with the overall focus of the study, the chapter concluded by exploring the relationships between term structures and macroeconomic indicators. It also emphasized the necessity of considering the topic from a globalization perspective by addressing cross-country interactions.

In the literature review chapter, the relationships between yield curves and macroeconomic indicators will be examined in greater detail. Yield curve estimating models will be reviewed, and empirical studies investigating the link between yield curves and macroeconomic indicators will be discussed. Finally, attention will be given to studies focusing on cross-country dynamics in yield curves. In this way, the chapter is intended to offer a preliminary understanding of the data and methods that the thesis may utilize, along with the scope of the empirical work.

2.1. SPREAD AND MACROECONOMIC VARIABLES

An analysis of the interest rates underlying the contracts resulting from the need for borrowing in an economy, based on their maturity structure, simultaneously offers insights into the expectations about that economy. In this framework, known as the yield curve, indicators such as the level of interest rates and the slope of the curve provide the opportunity to make inferences about the economic conditions. As a result, the yield curve and macroeconomic indicators are intrinsically linked.

In literature, some studies do not predict a yield curve but instead use the interest rates at the short and long ends of the yield curve and take the difference between them. This difference, referred to as the spread, is associated with macroeconomic indicators, and

the relations between them are interpreted. The use of spreads comes after the long-standing practice of using short-term interest rates to predict economic activity.

In their paper, Stock and Watson (2003) conducted a comprehensive literature review. They mentioned that, in the studies conducted, spreads can be calculated with using different maturities. Among these studies, many focused on the relationship between spreads and, interest rates, economic activity, and inflation rates. Moreover, studies incorporating default spreads, stock prices, dividend yields, and various other financial indicators were also discussed. In these studies, it is notable that spreads were used as an indicator for identifying economic recessions.

In their studies, Sims (1980) and Bernanke and Blinder (1992), who argued that monetary aggregates have low explanatory power for economic activity, used short-term interest rates. In the first study, monthly frequency data was used to predict short-term interest rates, money supply, wholesale price index, and industrial production by using unconstrained least squares. In the second study, indicators such as industrial production, capacity utilization, employment, unemployment rate, housing starts (statistics of new residential construction), wages, consumption, and durable goods were used to examine the relationships with monetary aggregates and short- and long- term rates through the Granger causality test. While traditional theories highlight the predictive power of monetary aggregates like money stock through anticipatory financial behaviour, these studies showed that the Federal funds rate is a more robust and less contaminated indicator of monetary policy, outperforming other rates and monetary measures in forecasting real economic variables—posing a challenge to real business cycle interpretations and underscoring the need for deeper exploration of monetary surprises in macroeconomic models.

Some studies found that changes in interest rates, rather than their level, have a higher explanatory power for economic activity, and propose to the adoption of spreads. For instance, Estrella and Hardouvelis (1991) use the spread that reflects the dynamic of the U.S. yield curve and analyse the relationship between spread and real GNP (Gross National Product) by using Ordinary Least Squares (OLS) regression method. According to the results by regressing the spread, which is the difference between the long-term 10-year bond yield and the short-term 3-month bond yield, with real GDP, they present

evidence that the slope of the yield curve can predict changes in real output. In addition, the analyses were conducted using leading indicators such as consumption, durable consumption, investment and public expenditures to strengthen the findings. A similar study belongs to the Estrella and Mishkin (1998). To predict the U.S. recessions, they also use the spread and construct a probit model. Furthermore, indicators from monetary aggregates to stock prices, interest rates to individual macro indicators (such as consumer prices, housing permits etc.) are used as well. This paper finds that the yield curve spread, and stock prices are reliable financial indicators for forecasting U.S. recessions, especially when used to supplement macroeconomic models, though their predictive power varies by horizon and highlights the importance of avoiding overfitting and carefully assessing out-of-sample performance. Mishkin (1990b, 1990c) focused on the relationship between spread and inflation rate of the U.S. in his studies. Accordingly, he found that the short-end (six months or less) of the yield curve had no relationship with inflation, while the long-end (greater than six months) showed that there was a significant relationship.

Estrella et al. (2003) examined the relationship between the yield curve and macroeconomic indicators (real activity and inflation) for the U.S. and Germany. In this study, spread is used to represent the yield curve. The relationship between spread and real economic activity and inflation is examined separately for both countries. Study suggests that models using the yield-curve spread to predict recessions are generally stable and reliable, whereas those predicting inflation, especially short-term changes, tend to be unstable. This pattern holds for both the U.S. and Germany. However, while recession prediction models can be trusted to some extent, all models require caution due to potential instability, influenced by factors like changes in monetary policy regimes. As a result, strict arguments about the relation between spread and recessions alone cannot guarantee its reliability. Hence, one can claim that better representatives for yield curve can be used.

The predictive power of the yield curve depends on the indicator used. Chinn and Kucko (2015) shed light on the debate on this issue. The article examines the yield spread's ability to predict economic growth and recessions. It finds that the yield spread is a significant predictor of one-year growth, though its effectiveness weakens for longer

periods, especially during the Great Moderation². The forecasting power is stronger in certain European countries, like Germany, and has improved with recent volatility. However, the yield curve's predictive power for recessions is inconsistent across countries. While the U.S. is an outlier, the yield curve's forecasting ability has rebounded before the Great Recession after a period of decline. Similar findings are also found in another study (Granát et al., 2023) which examined wider country set. Granát et al. (2023) researched whether the spread of the yield curve, which they claimed is a significant predictor for the U.S. recessions, is also applicable to 13 European economies (Belgium, Bulgaria, Czechia, France, Germany, Ireland, Italy, Poland, Portugal, Romania, Spain, Switzerland and the U.K.), concluding spread is reliable only for certain economies (Bulgaria, Ireland, Portugal, Spain, Switzerland and the U.K.). This study has reached these results by using a probit model. Furthermore, in the study conducted using various yield differences (spreads), it is claimed that the best predictor is 7 years minus 1 year difference.

Despite being used as an important indicator, in time, it is understood that spreads cannot always serve as a reliable indicator that produces consistent results. Therefore, there is a growing need for indicators that may better reflect the yield curve. On the other hand, it is observed that studies conducted up to a certain period were generally carried out on a single country, or group of country but individually. Cross-country comparisons are often discussed based on findings from individual countries.

² The "Great Moderation" refers to a period of stable economic growth, low inflation, and fewer recessions from the mid-1980s to the mid-2000s, particularly in the U.S. It was driven by factors like independent monetary policy, globalization, and technological progress. However, this era ended with the 2008 Global Financial Crisis, exposing vulnerabilities in the global financial system.

2.2. METHODOLOGIES FOR YIELD CURVE ESTIMATION

At this point, it would be beneficial to review the approaches for estimating the yield curves due to better representation requirement. According to Ioannides (2003), there are two approaches for modelling the yield curve: a parsimonious representation defined by an exponential decay term and a spline-based models that can be implemented in both parametric and non-parametric forms.

The first, known as term structure consistent modelling, aligns with the expectations hypothesis. This approach suggests that the pricing and hedging of all interest rates can be achieved and remain consistent with an initial estimate of the forward or spot yield curve. In other words, interest rates must be defined for each maturity in a specific period and must be linked to the initial interest rate at the beginning of these time periods. One of the leading studies on this approach belongs to Nelson and Siegel (1987). By using a second order differential equation, they estimated a yield curve from the U.S. treasury bills. This equation, by using the Laguerre function, consists of a polynomial multiplying with an exponential decay term, and is a mathematical class of approximating function. The model, which will be discussed in detail in the methodology section, suggests that a yield curve can consist of 3 factors: a constant value (β_0), a value that predicts the direction of the curve (β_1), and a value that represents the turning point on the curve (β_2). This model is capable to predict the hump shape structure of the curve, if it exists. Another article used this approach belongs to Svensson (1994). For the 1992-1994 period, forward interest rates are used to estimate the Sweden's yield curve. This model essentially extended the Nelson and Siegel model by adding new factor (β_3). New factor provides to reach a second hump in the curve. Thus, the goal has been to use a more flexible version of the model. Pooter (2007) states that most of the research primarily concentrates on the original three-factor Nelson-Siegel model. Extensions, such as the Svensson model, have been explored for their in-sample performance, while other extensions like those by Björk and Christensen (1997) have remained largely unexplored. Björk and Christensen (1997) propose an exponential-polynomial type model which also consists of Nelson-Siegel model as a special case. This extended representation also provides necessary and sufficient conditions for the consistency of the Nelson-Siegel model.

The second approach involves spline representations, which approximate the yield curve by fitting piecewise polynomials to bond prices or yields across maturities. However, sometimes methods that only provide smoothing between points have been used. McCulloch (1971) developed a technique by using discount function to fit a smooth curve on the yields of the securities. Discount function is the present value of one unit payment in future. Due to the discount functions assumed as continuous and monotonically decreasing in maturity (means as maturity becomes shorter, the present value (discount factor) increases), it becomes possible to define a “k” order function that continuously differentiable. Once a continuous discount function is defined, it will be estimated by linear regression. However, in the end, the judicial choice stands out regarding the selection of k. As the degree of the polynomial decreases, the predictive power of the discount function diminishes, while as the degree increases, although the residuals from the regression decrease, the degrees of freedom also decrease. This reduces the predictive success of the regression. McCulloch (1975) then extended this technique to include securities that differ in terms of tax, using the tax-free discount function. Vasicek and Fong (1982) model the term structure by using exponential splines. By deriving a non-linear discount function using spot and forward rates, they linearize it with a piecewise polynomial and differentiate themselves from McCulloch. Another brand of this approach uses non-parametric splines. According to Adams and van Deventer (1994), if the forward rate curve is a function of a specified form with a finite number of parameters, then a maximum smoothness for a term structure within this parametric family can be find. Thus, they suggest a maximum smoothness technique. It is also emphasized that success of this technique can be judged by intuitive interpolation, and it may not be the best smoothing technique for the forward rate curve. Fisher et al. (1995), also uses smoothing spline technique instead of regression splines. Further they incorporate a penalty for excess roughness and a single parameter controls the size of the penalty. Thus, by using Monte Carlo simulations they exhibit how to fit smoothing splines to an arbitrary transformation of the term structure of interest rates. Tanggaard (1997) introduces a new nonparametric method for estimating the term structure from coupon bond prices. The method uses a penalized least squares approach, resulting in a natural cubic spline. An iterative procedure is provided to solve the non-linear first-order conditions. The yield curve has no predefined constraints, aside from smoothness, and both the placement of the knots

and the degree of smoothness are determined by the data. The method was later tried on Danish government bonds from 1985 to 1994. Waggoner (1997) also uses a smoothed spline, but with a roughness penalty can vary across maturities, to estimate the forward rate curve. It has been emphasized that while the McCulloch method produces much more practical results, in contrast, the proposed method allows for controlling the degree of smoothing, which leads to a result that fits slightly better than McCulloch's approach.

Various studies also compare the methods and focus on which one performs better. Ioannides (2003) focused to estimate UK yield curve between 1995-1999 through seven methods derived from two main approaches; Nelson-Siegel, Svensson, McCulloch cubic spline, the linear, exponential, integrated exponential B-splines and the Variable Roughness Penalty (VRP). According to results, study suggests that the parsimonious specifications (which are Nelson-Siegel and the Svensson extension) and VRP method perform better than the linear spline counterparts.

Alper et al. (2004) compared monthly yield curves estimated for Türkiye by using both spline-based method of McCulloch and parsimonious model of Nelson-Siegel. According to results, study suggests that McCulloch method has superior in-sample properties³, whereas Nelson-Siegel method has superior out-of-sample⁴ properties. Specifically, the Nelson-Siegel method fits better in the middle region of the yield curve. Akıncı et al. (2006) used the Svensson extension of Nelson-Siegel method with high-frequency data to forecast the Türkiye's yield curve. The study highlights the Treasury's use of long-term fixed-coupon bonds to predict the yield curve, allowing for the estimation of zero-coupon yields up to five years. According to authors, Türkiye's yield curve is relatively short compared with other countries, but it will lengthen as the Treasury continues issuing fixed-coupon bonds, improving the maturity distribution and enabling more accurate yield predictions.

Diebold and Li (2006) re-interpreted the Nelson-Siegel method by defining factor structure for the data of U.S. treasury yields from 1985 to 2000 and explored the model's performance in out-of-sample forecasting. Model performance was compared with the results obtained from different methods (such as random walk, slope regression, AR(1)

³ In-sample means that the data is used to train the model.

⁴ Out-of-sample means that data is used to test the model's performance and generalization ability.

on yield levels, VAR(1) on yield levels etc.). According to results, although Nelson-Siegel method does not produce distinctive results compared to other methods within 1-month-ahead forecasting, but it performs better 1-year-ahead forecasting.

Advancements in forecasting techniques have allowed for various studies on the yield curve. Moreover, observing the behaviour of the yield curve provides the ability to predict economic trends. Studies highlight that the Nelson-Siegel method is a highly effective forecasting technique. Therefore, when examining the connections between yield curves and macroeconomic indicators, the importance of predictions made using the Nelson-Siegel method becomes evident.

2.3. RELATIONS BETWEEN ESTIMATED YIELD CURVES AND MACROECONOMICS

When choosing a method for yield curve forecasting, the objective must be clear. While a yield curve to be forecasted for high-frequency trading is expected to respond quickly to instantaneous price changes, a yield curve exhibiting more rigid behaviour will be sufficient for a researcher examining its relationship with macroeconomics. To this purpose, for instance, Gürkaynak et al. (2007) express that their aim while estimating the yield curve is to understand its fundamental determinants (such as macroeconomic conditions, monetary policy prospects, perceived risks and investors' risk preferences). Hence, they follow the Svensson extension of Nelson-Siegel model to forecast a long-term US yield curve from 1961 to present.

Diebold et al. (2006) examined the relationship between the yield curve and macroeconomic variables of the U.S. from 1972 to 2000. In this study, the average of bid and ask prices of treasury securities that have maturities from 3 month to 120 month are used. Yield curve is estimated by using Nelson-Siegel three-factor term structure model. On macroeconomic variables, they use manufacturing capacity utilization, federal funds rate and annual price inflation. By using Vector Auto Regression method results suggest that there are bidirectional relationships between yield curve and macroeconomic variables for the United States.

Morales (2008) studied the relationship between yield curve and macroeconomic variables for the Chilean economy for 1996 and 2001 through VAR method. While the

yield curve is estimated by using Diebold-Li interpretation of Nelson-Siegel method, monetary policy, inflation and economic activity are used as observable macroeconomic aggregates. According to the results, monetary policy rate responds significantly to the yield curve factors. Both the level and slope of the yield curve react to real activity and monetary policy shocks; study highlights the importance of considering these factors for effective policy implementation.

Fernandes and Vieira (2019) aimed to enhance yield curve estimation by increasing the number of factors. The study highlights that improving yield curve forecasts requires using a large number of forward-looking variables. It proposes forecasting the U.S. yield curve using a Factor-Augmented Dynamic Nelson-Siegel (FADNS) model, which outperforms existing models in out-of-sample tests. In the study, 86 macroeconomic indicators from 1989 to 2015 were used, and their principal components were extracted. Using these data, along with yields of different maturities in the FADNS model, the components of the yield curve (level, slope, and curvature) were obtained. The FADNS results are also compared with other methods (Random Walk, Auto Regression, Slope model, VAR model as in Diebold-Li, etc.). This analysis is then repeated using data at monthly and weekly frequencies. The study suggests that while the AR and RW models are challenging benchmarks, FADNS performs better as the forecast horizon lengthens.

A study focusing on the Turkish economy both in yield curve and macroeconomic linkages belongs to Kaya (2010). The study forecasts Turkey's yield curve for the period between 1993 and 2009 according to the Diebold-Li method. In the second part of the study, the correlations between the forecast results and macroeconomic variables (inflation, growth, capacity utilization, USD exchange rate changes, real effective exchange rate, policy interest rate, Borsa Istanbul index changes, budget deficit, domestic borrowing, capital account, and current balance) are examined. As a result, it is claimed that post-2002 period macro variables play vital role in yield curve. Furthermore, study claimed that the inflation rate and changes in the exchange rate are two important macro indicators in determining the shape of the yield curve. Another study focuses on Türkiye's yield curve and macroeconomic relations belongs to Tüzün and Kahyaoğlu (2021). For the 2003M02-2018M05 period, Türkiye's yield curve is estimated by using Svensson extension of Nelson-Siegel model. Then, the relationship between macroeconomic

indicators and yield curve factors is examined by using Threshold Vector Autoregression (TVAR) approach. Study reveals that the level parameter explained highly with inflation rate, while the slope parameter is influenced by output gap. However, the analysis also identifies the asymmetric effects of macroeconomic variables on yield curve parameters in Türkiye. It highlights that external shocks predominantly shape the yield curve, signalling the economy's vulnerability. As a result, the study emphasizes that policymakers should consider the asymmetric effects when making decisions.

2.4. GLOBAL INTERDEPENDENCIES IN YIELD CURVES

The relationship between the spread, which is used to represent the yield curve, and dynamics such as economic activity and inflation has been studied. With the assumption that the spread may not always be a reliable indicator, yield curve forecasting methods have come to the forefront. The predicted models have been associated with macroeconomic indicators, and the connections between them have been examined. In most country-specific studies, the relationship of yield curves between countries has been relatively less emphasized. In this section, studies examining whether the yield curves of different countries have relation with other countries' yield curves have been reviewed.

Some studies in the literature explore whether the yield curves interact with each other. For instance, Diebold et al. (2008) answered the effects of global interdependencies in yield curves by extending the Diebold-Li (2006) model. By incorporating a set of country yield curves (Germany, Japan, the U.K. and the U.S.) for the 1985M09 to 2005M08 period, study aims to estimate the global yield model and extracts the global yield factors. The study finds that global yield level and slope factors significantly impact country bond yields and are linked to global macroeconomic fundamentals like inflation and real activity. Study also emphasizes that curvature factor lacks clear links to macroeconomic fundamentals.

In a study by Mehl (2009), the slope of yield curves in emerging economies was used to predict inflation and growth rates. The study looked at the slope as the spread of the yield curve, rather than estimating a yield curve. It's important to note that the study tries to connect countries by assuming that the yield curves of the US and the Eurozone might contain information about inflation and economic activities in emerging countries. The

study focused on 14 emerging economies, including Brazil, Czechia, Hong Kong, Hungary, India, South Korea, Malaysia, Mexico, the Philippines, Poland, Saudi Arabia, Singapore, South Africa, and Taiwan. It used German bond yields as a representative for the Eurozone's yield curve. The study found that the slopes of the U.S. or Eurozone yield curve are better predictors of inflation than the domestic slopes in emerging economies for about half of the countries, and for growth, they work better for two-thirds of the countries. Study reached these results by using Mean Squared Forecast Error (MSFE) methodology based on Stock and Watson (2003)

A study that shows the yield curves of countries can affect each other, and their macroeconomic indicators belongs to Lange (2014). The study estimates yield curves for both the U.S. and Canada using the Diebold-Li method for the period from 1986 to 2010 based on both Canadian and the U.S. bond yields. In the study, the capacity utilization rate (as representor of real economic activity), inflation rate (the 12-month change in the price index), overnight interest rates (as a monetary policy indicator), and exchange rate are used as macroeconomic indicators. In its strategy, the study assumes that the U.S. term structure of interest rates is exogenous of both the Canadian yield curve and the macroeconomic indicators. As a result, the empirical findings indicate a strong relationship between the yield curves of the two countries, with the U.S. yield curve explaining up to 45 percent of the variation in the level, and approximately 30 percent of the movements in the slope and curvature of the Canadian yield curve. Canadian yield-curve factors are shown to account for around 50 percent of the variation in output and the monetary policy rate, and roughly 25 percent of the variation in inflation.

Another paper explores the interactions of yield curves of countries by using a different strategy. Jotikasthira et al. (2015) explores the co-movement of the yield curves across different currencies and maturities, modelling interest rates in the U.S., the U.K., and Germany using an affine model. For the period 1987-2008, data at monthly frequency is used to obtain yield curve pricing factors through principal component analysis. The correlations of all series are examined along with macroeconomic indicators such as the inflation rate and industrial production. At the end, it finds that global inflation and the U.S. yield levels explain over 70 percent of the cross-country covariance in bond yields. The paper decomposes this into policy and risk compensation channels, showing that the

latter plays a greater role in longer maturities. However, it claims that challenges remain in identifying the policy channel, especially with unconventional bond purchasing programs.

Kaya (2017) used a panel VAR method to find empirical evidence between macroeconomic variables and yield curve with a cross-country perspective. By using macroeconomic variables (output gap, inflation rate and policy rate) and yield curve factors of 9 advanced countries (Australia, Canada, Germany, Japan, Norway, Sweden, Switzerland, U.K. and the U.S.) from 1990M01 to 2009M06, study claims a bidirectional relationship between both inter-countries and country specific yield curve and macroeconomic variables. The study finds a bidirectional link between yield factors and macroeconomic variables of countries. While the yield curve's level is influenced only by the policy rate, its slope is affected by all three macroeconomic factors. The level of the yield curve has no significant impact on macro variables, but the slope affects inflation and policy rates in the short term. Additionally, the curvature of the yield curve strongly influences future macroeconomic developments.

In their study focused on Brazil, Stona and Caldeira (2019) conducted an analysis using the yield curve parameters of the U.S. and Brazil along with Brazil's macroeconomic variables. This study examines Brazilian term structure dynamics from 2004 to 2016, revealing a bidirectional relationship between the macroeconomic indicators and the yield curve. Findings emphasize the correlation between the level factors of Brazil and the U.S., especially the influence of the U.S. level factor on the Brazilian slope. The U.S. yield curve factors explain nearly half of the variance in the level factor and have a similar impact as macroeconomic factors on explaining the slope and curvature in the long-term. These results enhance understanding of the U.S. influence on emerging economies. The paper reaches these results by using the Dynamic Nelson-Siegel (DNS) model, enhanced with macroeconomic factors.

Ito and Tran (2021) questions the challenges of emerging market economies face while trying to manage the yield curve in financially globalized world. They do not estimate a yield curve but focuses on how the net capital inflows contribute to weakening the link between short- and long-term interest rates for any country. With this perspective, the study uses data from 132 countries, which 109 is developing countries, for the 1978-2016

period. Together with capital flows, study also utilizes macroprudential policies as dummy variables. The study uses Ordinary Least Squares (OLS) and Two Stage Least Square (2SLS) methods while analysing the countries. The results indicate that economies with greater financial openness or more advanced financial markets tend to experience a stronger negative relationship between net capital inflows and the pass-through effect from short-term to long-term interest rates. Moreover, the findings suggest that in developing countries with more open financial markets, long-term assets are more vulnerable to shocks originating from the central economy (i.e. the U.S.), regardless of the exchange rate regime in place.

Ahmed and Chinn (2023) questioned that the foreign yield curves as a predictor of US recessions and Gross Domestic Product (GDP) growth. They contribute to the literature by demonstrating that yield curves outside the U.S. provide unique insights into U.S. recessions. To achieve this, the study uses the non-U.S. members of the G-7 countries (Canada, Germany, Japan, and the U.K.). From 1979 to 2021, the term spread between long-term and short-term interest rates is used to represent the yield curves of these countries. Probit regressions are applied to analyse the relationship between the U.S. recessions and foreign yield curves. According to the results, the foreign term spread (as the average of quarterly term spreads of G-7 constituents Canada, Germany, Japan, and the U.K.) is a more effective short-term predictor of the U.S. recessions than the U.S. term spread. Both spreads predict the U.S. recessions at different timeframes and influence the U.S. economic activity in distinct ways. When the U.S. term spreads decrease, the U.S. Dollar appreciates significantly, suggesting that the U.S. economic conditions spill over to other countries. While smaller foreign term spreads also signal the U.S. recessions, they lead to much less depreciation of the U.S. Dollar. Furthermore, smaller foreign term spreads result in a notable decline in foreign direct investment (FDI) to the U.S., a pattern not seen with smaller the U.S. term spreads. Overall, these findings highlight how the U.S. recession risks affect global economic growth and reduce foreign demand for the U.S. exports and investment.

Early studies focused on using interest rates instead of monetary aggregates to predict economic activity. However, due to the maturity mismatch, the general predictive power of interest rates has decreased. As a result, the spread representing the yield curve has

become widely used over a certain period. Nevertheless, because the relationship between the spread and economic activity or inflation did not yield consistent results across different countries, it has lost its reliability as an indicator. This has increased interest in developing models for yield curve prediction. The prediction methods that have developed from two main branches provide approaches for yield curve forecasting that can contribute significantly to economic research. The other branch, which requires working with higher-frequency data, has developed as a forecasting method aimed at assisting finance professionals, especially in trading. The branch following the Nelson-Siegel model and its extensions has facilitated the forecasting of yield curves in subsequent studies, as well as the establishment of relationships between yield curves and macroeconomic indicators. Recent studies primarily focus on the interactions between countries through their yield curves. According to the findings of this comprehensive literature review, there are bilateral relationships when examining the interactions between different countries using yield curves and macroeconomic indicators. Therefore, a broad area has been opened for researchers to investigate these relationships across different countries and time periods.

This thesis makes several important contributions to the existing literature. First, the study investigates how Türkiye's yield curve responds to changes in the yield curve factors and macroeconomic variables of both in Türkiye and in other countries.. Second, in contrast to similar studies in the literature, this research employs the Global Vector Autoregression (GVAR) methodology. The rationale for utilizing the GVAR approach lies in its capacity to capture the interactions between countries, which are transmitted through trade channels. Third, the study makes use of an extensive dataset that includes 19 countries which are introduced in detail on data section of empirical analysis chapter. In this respect, the study contributes to the literature in this field as it largely covers emerging economies. The inclusion of multiple countries is also essential for assessing the impact of globalization on Türkiye through the interlinkages between yield curves and macroeconomic variables. As of the period covered by the study, the selected countries account for 57.8 percent of global GDP based on purchasing power parity, with this share steadily increasing over time.

CHAPTER 3

DATA AND METHODOLOGY

In previous chapter, the comprehensive literature review has revealed the contributions of researchers to the field of yield curve analysis, both from a historical perspective and within the scope of the term structure of interest rates. In this section, as also outlined in the introduction, an empirical application addressing the research question and the literature will be presented. First, information regarding the selection of indicators and the time period to be used will be provided. The manner in which the indicators are employed and the sources from which they are obtained will be detailed. Subsequently, the econometric background of the method used for yield curve estimation, as well as the Global Vector Autoregression (GVAR) framework that integrates all data, will be presented. Finally, an explanation of Impulse Response Functions will be provided, with particular attention given to the rationale behind the use of the Generalized Impulse Response Function and Orthogonalized Impulse Response Function.

3.1. DATA AND MODEL SELECTION

The area where international relations are studied both through yield curves and macroeconomic indicators is relatively new and has been explored to a limited extent. The literature highlights the lack of studies especially conducted with developing countries. This study utilizes a panel including data from 19 countries: the United States, Brazil, Bulgaria, Chile, China, Colombia, Hungary, India, Indonesia, Malaysia, Mexico, Poland, Romania, Russia, South Africa, South Korea, Thailand, Türkiye, and Vietnam.

The selection of countries is based on the IMF's classification of developing economies. South Korea, although typically categorized as developed country, is included in dataset due to the fact that the country is classified as developing country by MSCI on the stock markets classification. The U.S., as a key player in the global bond market, is also included despite being an advanced economy.

A yield curve forecast will be constructed for each country utilizing bonds of varying maturities sourced from multiple national markets. Consistent with the existing literature

and given its frequent use in economic research, the application of the Diebold-Li method, which is derived from the Nelson-Siegel framework, is considered appropriate for this study. The mathematical details of the method will be discussed later in the methodology section.

The shallow depth of bond markets or insufficient data availability has been a restrictive factor for the country selection. Therefore, a significant share of the developing countries is required to be excluded from the dataset. To forecast the yield curves, time series of bond rates are collected from Bloomberg Terminal and Investing.com. Inconsistent data points (bond yields for maturities that are not traded, missing data, or inconsistent data between two sources etc.) excluded from the analysis. The maturity breakdown of the bonds that are used in the study is shown in Table 1.

Table 1. Maturity Breakdown of the Bills & Bonds by Country

Countries	Bonds by Maturity	Countries	Bonds by Maturity
USA	Monthly [1,3,6] Yearly [1, 2, 3,5,10,30]	Mexico	Monthly [1,3,6,9] Yearly [1,3,5,7,10,15,20,30]
Brazil	Monthly [9], Yearly [1,2,3,5,10]	Poland	Monthly [1,2], Yearly [1,2,3,4,5,10]
Bulgaria	Yearly [1,2,3,4,5]	Romania	Monthly [6], Yearly [1,3,5,10]
Chile	Yearly [1,2,3,5]	Russia	Yearly [1,2,3,5,10,15]
China	Yearly [1,2,3,5,7,10,15,20]	South Africa	Monthly [3], Yearly [2,5,10,15,20,30]
Colombia	Yearly [2,5,10]	South Korea	Yearly [1,2,3,4,5,10]
Hungary	Yearly [1,3,5,10,15]	Thailand	Yearly [1,2,5,7,10,12,14]
India	Yearly [1,3,4,5,6,7,8,9,10,15]	Türkiye	Monthly [3,6,9], Yearly [1,2,3,4,5,10]
Indonesia	Yearly [1,3,5,10,15,20]	Vietnam	Yearly [1,2,3,5,7,10,15]
Malaysia	Yearly [3,5,10]		

Source: Bloomberg Terminal, Investing.com

Macroeconomic indicators include each country's industrial production, inflation rate, policy interest rate and stock indices series. In line with the literature, industrial production is used to represent real economic activity in any country, while the inflation rate has been included due to its close relationship with interest rates. Industrial production and inflation rate series are obtained from the World Bank's Global Economic Monitor (WB GEM) database. As an additional economic activity indicator, stock market index series are used and obtained from Bloomberg Terminal.

Modern central banking aims to influence the short end of the yield curve when implementing monetary policy. Therefore, the effectiveness of the policies applied can be interpreted through the relationship between the yield curve and macroeconomic indicators. In this context, policy interest rates have been included among the macroeconomic indicators. The policy interest rate series is sourced from the Bank for International Settlements (BIS) statistics monthly.

The study uses all the data at monthly frequencies. Seasonally adjusted industrial production series (in constant 2010 USD) and stock market indices are utilized based on their monthly changes. Percentage changes are used in econometric analysis to allow for scale-invariant comparisons and better capture proportional relationships between variables. Table 2 presents the data that are utilized in the analysis.

Table 2. Variables in the GVAR Model

Variables	Abbr.	Specifications	Source
Level	L	Monthly, percent	Obtained from bond series
Slope	S	Monthly, percent	Obtained from bond series
Curvature	C	Monthly, percent	Obtained from bond series
Industrial Production	INDPRO	Constant prices at 2010, \$, seas.adj., monthly change	WB GEM database
Inflation rate	INFRA	Consumer price index, Nominal seas.adj., monthly change	WB GEM database
Policy rate	POLRA	Monthly, percent	BIS
Stock index	STOCK	Monthly change	Bloomberg Terminal
Trade volume	-	\$, used on weight matrices	WITS

The study analyses data spanning from 2008 to 2021. The period prior to 2008 has been excluded from the analysis due to the limited availability of bond market data for developing countries during that time, as well as the absence of a comprehensive exploration of the effects of increasing economic integration. The dataset ended in 2021, to exclude, as much as possible, the effects of global lockdowns caused by the Covid-19 pandemic.

As will be explained in detail in the GVAR methodology section, bilateral trade data was used to relate the indicators between countries. To do that the study requires the construction of weighting matrices. These matrices are derived from bilateral export

volume data for each country. Bilateral export data is sourced from the World Integrated Trade Solutions (WITS) database, which is developed in collaboration with various organizations under the auspices of the World Bank. The export volumes are weighted on an annual basis to cover the period from 2008 to 2021, resulting in a total of 14 distinct weighting matrices. The trade weights matrices derived from yearly data is also consistent with the literature on the use of the GVAR method. For instance, Mohaddes and Raissi (2024) applied GVAR analysis using annual trade volume data, while having obtained quarterly macroeconomic indicators in their study.

3.2. ECONOMETRIC METHODOLOGY

3.2.1. Yield Curve Estimation

To uncover the information within a yield curve, Nelson and Siegel (1987) developed a method that allows for the estimation of a time-dependent yield curve from bonds with various maturities. This method is essentially a decomposition aimed at revealing the components that make up the yield curve. The equational representation of the methodology is given below;

$$r(m) = \beta_0 + \beta_1 \cdot \exp(-m/\tau_1) + \beta_2 \cdot \exp(-m/\tau_2) \quad (1)$$

where m is maturity, $r(m)$ is instantaneous forward rate, τ_1 and τ_2 time constants, β_0 , β_1 and β_2 are coefficients determined by initial conditions. This equation generates a family of forward rate curves that take different shapes depending on the values of β_1 and β_2 . To evolve the model more parsimonious state (reducing overparameterization), it is possible to write the same model as;

$$r(m) = \beta_0 + \beta_1 \cdot \exp(-m/\tau) + \beta_2 \cdot [(m/\tau) \cdot \exp(-m/\tau)] \quad (2)$$

Due to $R(m) = 1/m \int_0^m r(x)dx$ where $R(m)$ reflects the average of forward rates, and model (2) can be seen as constant plus a Laguerre function, it is possible to write equation (2) as in equation (3). While these functions are used for generalization of higher-order models, it provides a useful mathematical method for approximating function.

$$R(m) = \beta_0 + (\beta_1 + \beta_2) \cdot [1 - \exp(-m/\tau)]/(m/\tau) - \beta_2 \cdot \exp(-m/\tau) \quad (3)$$

Equation (3) shows the Laguerre transformation of equation (2) where limiting the value of $R(m)$ is β_0 as m gets large and it is $(\beta_1 + \beta_2)$ as m gets small.

By using Nelson-Siegel model in equation (3), Diebold and Li (2006) define the three-factors parameter estimation as follows;

$$y_t(\tau) = \beta_{1t} + \beta_{2t} \left(\frac{1-e^{-\lambda_t \tau}}{\lambda_t \tau} \right) + \beta_{3t} \left(\frac{1-e^{-\lambda_t \tau}}{\lambda_t \tau} - e^{-\lambda_t \tau} \right) \quad (4)$$

These three factors are then called as Level (L), Slope (S) and Curvature (C) instead of β_1, β_2 and β_3 (Diebold et al. 2006). Comparing equations (3) and (4), y corresponds to R , t to m and $1/\tau$ to λ .

$$y(\tau) = L_t + S_t \left(\frac{1-e^{-\lambda \tau}}{\lambda \tau} \right) + C_t \left(\frac{1-e^{-\lambda \tau}}{\lambda \tau} - e^{-\lambda \tau} \right) \quad (5)$$

In equation (5), L_t represents the base yield of a bond as maturity extends to infinity, and an increase in L_t equally raises yields across all maturities. Thus, it alters the level of the yield curve. S_t equals the difference between the yield of a bond as maturity extends to infinity and the yield when maturity is 0 (Frankel and Lown, 1994). An increase in S_t raises short-term bond yields compared to long-term ones, implying a change in the slope of the yield curve. Therefore, S_t means "short-term minus long-term," indicates a negatively signed slope of the yield curve. Following Diebold et al. (2006), for clarity in expression, S_t is referred as the slope variable and read as "short-term minus long-term." Finally, the expression $\left(\frac{1-e^{-\lambda \tau}}{\lambda \tau} - e^{-\lambda \tau} \right)$ starts from 0, increases over time, and then approaches zero again. Therefore, an increase in C_t predominantly affects medium-term yields while having minimal impact on short-term and long-term returns. Hence, C_t is considered as the curvature variable.

These factors summarize the characteristics of a yield curve: the level, which indicates the long-term constant rate or risk-free interest rate; the slope, which shows the direction (or the shape that interest rates will take depending on their maturities); and the curvature, which represents the turning points in the curve. The level provides information about the general level of interest rates in the economy. The slope allows for comparisons of current and future interest rates. The curvature, on the other hand, contains information about potential changes in interest rates and the direction that the curve will take.

A change affecting the level of a yield curve implies a parallel shift, indicating a simultaneous increase or decrease in interest rates across all maturities. Such a shift also reflects a change in the general level of risk-free interest rates. The risk-free interest rate is a theoretical concept representing the rate of return an investor expects from an investment without default risk, and in practice, it is often taken as the yield of government bonds. Factors leading to change in long-term constant rate include monetary policy, inflation expectations, market risk perceptions, and global factors. Tightening monetary policy by raising short-term interest rates can increase risk-free interest rates by shifting the yield curve upward in parallel. Expectations of higher inflation may lead economic decision-makers to demand higher returns to compensate for decreased purchasing power, resulting in an upward shift in the yield curve. Investors may demand higher returns to hold bonds from any maturity if they perceive increased market risks. This may lead an upward shift in the yield curve across all maturities. Global factors can also cause parallel shifts in yield curves. For instance, during a global crisis, increased demand for government bonds at all maturities relative to corporate bonds can elevate rather than reduce risk-free interest rates due to heightened global risk perceptions, creating a positive level effect on a sovereign yield curve.

The economic interpretation of changes in slope and curvature is more complex compared to changes in level. The slope factor of the yield curve, unlike the spread, is a forecasted component of the yield curve. However, in terms of economic meaning, they have similar definitions. In this regard, while the spread looks at the difference between short-term and long-term interest rates, the slope factor can be interpreted by examining the forecasted value. For example, low forecasted values of the slope factor suggest that, for firms, investing now is more costly than investing in the future, and for individuals, spending today is less reasonable than spending in the future. Conversely, high forecasted values of the slope may lead firms to bring forward their investment decisions and individuals to save less and consume more. Therefore, the value of the slope can contain significant information about economic activity.

The curvature factor shows the fluctuations in the yield curve. Although it is more conceptual compared to other yield curve factors, a change in curvature reflects the situation where economic units alter their decisions during business cycles. Despite this

explanation, the relationship between the curvature and economic indicators remains unclear. Indeed, in their study, Diebold et al. (2008) stated that 'there is a lack of a clear relationship between the curvature factor and macroeconomic fundamentals.'

The λ in Equation (5) represents the exponential decay factor. When the estimated exponential decay factor, along with level, slope, and curvature, takes on low values, the curvature is less pronounced, leading to better long-term fit. Conversely, higher values result in faster curvature decay, providing better short-term fit. This factor also determines the maximum values that the curvature factor can attain. However, the use of λ varies depending on the purpose. According to Lange (2014) decay parameter is fix in Diebold and Li (2006) study due to maximize the loading on the medium-term factor at 30 months. Thus, a fixed λ will allow them to use a two-step approach to estimate the transition and measurement equations separately using OLS. In contrary, Lange (2014) prefers the parameter λ is freely estimated along with the other factors (level, slope and curvature) in the loading matrix using a one-step approach that estimates all parameters simultaneously as in Diebold et al. (2006). Within the scope of this explanation, in this study, the λ parameter will be estimated freely together with other factors. Finally, the parameter t , used as a subscript in level, slope, and curvature parameters, denotes the date on which the bond is traded.

The yield curve estimation according to equation (5) is the first backbone of this study. The three latent factors obtained from each country's various bonds will be used as yield curve inputs of the GVAR model while analysing with macroeconomic variables.

3.2.2. Global Vector Auto Regression (GVAR) Methodology

The second backbone is the GVAR methodology which firstly implemented by Pesaran, Schuermann and Weiner (2004). The use of the GVAR analysis can change according to the purposes that the conducted study expected to reach. GVAR modelling is a special framework combined a set of individual Vector Auto Regression (VAR) models or Vector Error Correcting Models (VECM).

Main differences between two are;

- VAR models the interdependencies among multiple time series, VECM models the short-term dynamics with long-term equilibrium relationships.
- VAR can be applicable to use with stationary data, VECM works with non-stationary but cointegrated data.
- VAR does not require cointegration while VECM requires among variables.
- While VAR does not include error correction term, VECM includes.
- VAR models are general models for dynamic systems, VECM models specialized for cointegrated systems.

VAR model is an empirical method that is proposed when we are not confident about a variable is exogenous or not (Enders, 2014). This study aims to observe the interactions between the yield curves of countries and macroeconomic indicators over the covered periods. In this context, relationships based on long-term equilibrium are not sought. To conduct an observation that does not rely on the cointegration of long-term series, individual VAR models have been used to obtain the GVAR solution. Although the study is based on the work of Pesaran et al. (2004) for the GVAR model solution, the individual country models have been constructed as VAR models rather than VECM, and the GVAR solution has been derived from these models.

The assumption is that there are $N + 1$ countries (or regions) in the global economy, indexed by $i = 0, 1, 2, \dots, N$. Country 0 is adopted as the reference country. For each country/region, it is assumed that the country-specific variables are related to the global economy variables measured as country-specific weighted averages of foreign variables plus deterministic variables, such as time trends, and global exogenous variables, such as oil prices. In a general form of first-order dynamic specification that relates the $k_i \times 1$ country-specific factors/variables, $\mathbf{x}_{it}$, and $\mathbf{x}_{it}^*$ is a $k_i^* \times 1$ vector of foreign variables specific to country i , and written as;

$$\mathbf{x}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{\Phi}_i\mathbf{x}_{i,t-1} + \mathbf{\Phi}_i\mathbf{x}_{i,t-2} + \mathbf{\Lambda}_{i0}\mathbf{x}_{it}^* + \mathbf{\Lambda}_{i1}\mathbf{x}_{i,t-1}^* + \mathbf{\Lambda}_{i1}\mathbf{x}_{i,t-2}^* + \varepsilon_{it} \quad (1)$$

where $\mathbf{\Phi}_i$ is a $k_i \times k_i$ matrix of lagged coefficients, $\mathbf{\Lambda}_{i0}$ and $\mathbf{\Lambda}_{i1}$ are $k_i \times k_i^*$ matrices of coefficients associated with the foreign specific variables, and ε_{it} is a $k_i \times 1$ vector of

idiosyncratic country-specific shocks. In the special case where $\Lambda_{i0} = \Lambda_{i1} = 0$, this model reduces to a standard VAR process of order 2, VAR (2). However, in the presence of foreign specific variables, (2) is an augmented VAR model, which is denoted by VARX*(2, 2).

In open form, $\mathbf{x}_{it}$ includes $\mathbf{x}_{it} = (L_{it}, S_{it}, C_{it}, INDPRO_{it}, INFRA_{it}, POLRA_{it}, STOCK_{it})$, while $\mathbf{x}_{it}^*$ includes foreign correspondences of domestic variables; $\mathbf{x}_{it}^* = (L_{it}^*, S_{it}^*, C_{it}^*, INDPRO_{it}^*, INFRA_{it}^*, POLRA_{it}^*, STOCK_{it}^*)$. It is also assumed that the idiosyncratic shocks, ε_{it} , are serially uncorrelated with mean $\mathbf{0}$ and a non-singular covariance matrix, $\Sigma_{ii} = (\sigma_{ii,ls})$ where $\sigma_{ii,ls} = cov(\varepsilon_{ilt}, \varepsilon_{ist})$, or in implicit form,

$$\varepsilon_{it} \sim iid(\mathbf{0}, \Sigma_{ii}) \quad (2)$$

The variables are arranged to monthly changes to exhibit same specifications with each other. While the Level, Slope, Curvature and Policy Rate are monthly basis variables expressed as percent, industrial production, inflation rate and stock indices are obtained as level and required to take percentage change with the following formulas;

$$INDPRO_i = \frac{INDPRO_{i,t}}{INDPRO_{i,t-1}} - 1, INFRA_i = \frac{INFRA_{i,t}}{INFRA_{i,t-1}} - 1, STOCK_i = \frac{STOCK_{i,t}}{STOCK_{i,t-1}} - 1 \quad (3)$$

Foreign variables are computed as weighted averages of corresponding domestic variables of all countries with the $\mathbf{x}_{it}^* = \sum_{j=0}^N w_{ij} \mathbf{x}_{jt}$, $w_{ii} = 0$ where w_{ij} is a set of weights with $j = 0, 1, \dots, N$ and $\sum_{j=0}^N w_{ij} = 1$. The weights are predetermined and are meant to capture the relation of country j for the i^{th} economy. In this study, it reflects the trade linkages. Share of bilateral export volumes between countries to total exports are used as trade weights while calculating the foreign variables, equations as follows;

$$\begin{aligned} L_{it}^* &= \sum_{j=0}^N w_{ij}^L L_{jt} \\ S_{it}^* &= \sum_{j=0}^N w_{ij}^S S_{jt} \\ C_{it}^* &= \sum_{j=0}^N w_{ij}^C C_{jt} \\ INDPRO_{it}^* &= \sum_{j=0}^N w_{ij}^{INDPRO} INDPRO_{jt} \\ INFRA_{it}^* &= \sum_{j=0}^N w_{ij}^{INFRA} INFRA_{jt} \\ POLRA_{it}^* &= \sum_{j=0}^N w_{ij}^{POLRA} POLRA_{jt} \\ STOCK_{it}^* &= \sum_{j=0}^N w_{ij}^{STOCK} STOCK_{jt} \end{aligned} \quad (4)$$

In general, the GVAR model allows for interactions among the different economies through three separate but interrelated channels:

1. Contemporaneous dependence of $\mathbf{x}_{it}$ on $\mathbf{x}_{it}^*$ and on its lagged values. In this study, up to 2 lags are allowed.
2. Dependence of the country-specific variables on common global exogenous variables, such as oil prices. As this study does not aim to investigate the impact of common global exogenous factors, such variables are not incorporated into the analysis.
3. Nonzero contemporaneous dependence of shocks in country i on the shocks in country j , measured via the cross-country covariances, $\mathbf{\Sigma}_{ij}$,

$$\mathbf{\Sigma}_{ij} = \text{cov}(\varepsilon_{it}, \varepsilon_{jt}) = E(\varepsilon_{it}\varepsilon_{jt}') \text{ for } i \neq j, \quad (5)$$

where ε_{it} is defined by (1). A typical element of $\mathbf{\Sigma}_{ij}$ will be denoted by $\sigma_{ij,ls} = \text{cov}(\varepsilon_{ilt}, \varepsilon_{jst})$ which is the covariance of the l^{th} variable in the country i with the s^{th} variable in the country j .

Because of the contemporaneous dependence of both domestic and foreign variables, individual VAR models need to be solved simultaneously for all the domestic variables $\mathbf{x}_{it}$, $i = 0, 1, \dots, N$. The solution can then be used for impulse-response analysis. While constructing the GVAR model from the individual VARs, a $(k_i + k_i^*) \times 1$ vector needs to be defined;

$$\mathbf{z}_{it} = \begin{pmatrix} \mathbf{x}_{it} \\ \mathbf{x}_{it}^* \end{pmatrix} \quad (6)$$

and the equation (1) is rewritten as;

$$\mathbf{A}_i \mathbf{z}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{B}_i \mathbf{z}_{i,t-1} + \varepsilon_{it} \quad (7)$$

where,

$$\mathbf{A}_i = (\mathbf{I}_{k_i}, -\mathbf{\Lambda}_{i0}) \text{ and } \mathbf{B}_i = (\mathbf{\Phi}_i, \mathbf{\Lambda}_{i1}, \mathbf{\Lambda}_{i2}) \quad (8)$$

Dimensions for $\mathbf{A}_{i0}$ and $\mathbf{B}_i$ are $k_i \times (k_i + k_i^*)$ and $\mathbf{A}_i$ has a full row rank, means $\text{rank}(\mathbf{A}_i) = k_i$.

The country-specific variables can be collected in the $k_i \times 1$ global vector $\mathbf{x}_t = (\mathbf{x}'_{0t}, \mathbf{x}'_{1t}, \dots, \mathbf{x}'_{Nt})'$, where $k = \sum_{i=0}^N k_i$ is the total number of endogenous variables in the global model. Recalling the;

$$\mathbf{x}_{0t} = (L_{0t}, S_{0t}, C_{0t}, INDPRO_{0t}, INFRA_{0t}, POLRA_{0t}, STOCK_{0t})'$$

and

$$\mathbf{x}_{it} = (L_{it}, S_{it}, C_{it}, INDPRO_{it}, INFRA_{it}, POLRA_{it}, STOCK_{it})'$$

for $i = 1, \dots, N$. The analysis is invariant to the way in which the endogenous variables are stacked in $\mathbf{x}_{it}$ and to the ordering of the countries in $\mathbf{x}_t$. Country-specific variables can all be written in terms of $\mathbf{x}_t$;

$$\mathbf{z}_{it} = \mathbf{W}_i \mathbf{x}_t, i = 0, 1, 2, \dots, N, \quad (9)$$

where $\mathbf{W}_i$ is a $(k_i + k_i^*) \times k_i$ matrix of time-varying constants defined in terms of the country-specific weights $w_{ij}^L, w_{ij}^S, w_{ij}^C, w_{ij}^{INDPRO}, w_{ij}^{INFRA}, w_{ij}^{POLRA}, w_{ij}^{STOCK}$. $\mathbf{W}_i$, in here, can be viewed as link matrix that allows the individual models to be written in terms of the global variable vector, $\mathbf{x}_t$. Using both equations (9) and (7), it can be obtained that;

$$\mathbf{A}_i \mathbf{W}_i \mathbf{x}_t = \mathbf{a}_{i0} + \mathbf{a}_{i1} t + \mathbf{B}_i \mathbf{W}_i \mathbf{x}_{t-1} + \boldsymbol{\varepsilon}_{it}$$

where $\mathbf{A}_i \mathbf{W}_i$ and $\mathbf{B}_i \mathbf{W}_i$ are both $k_i \times k$ -dimensional matrices. Arranging these equations in sequence results in;

$$\mathbf{G} \mathbf{x}_t = \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{H} \mathbf{x}_{t-1} + \boldsymbol{\varepsilon}_t \quad (10)$$

where,

$$\mathbf{a}_0 = \begin{pmatrix} \mathbf{a}_{00} \\ \mathbf{a}_{10} \\ \vdots \\ \mathbf{a}_{N0} \end{pmatrix}, \mathbf{a}_1 = \begin{pmatrix} \mathbf{a}_{01} \\ \mathbf{a}_{11} \\ \vdots \\ \mathbf{a}_{N1} \end{pmatrix}, \boldsymbol{\varepsilon}_t = \begin{pmatrix} \boldsymbol{\varepsilon}_{0t} \\ \boldsymbol{\varepsilon}_{1t} \\ \vdots \\ \boldsymbol{\varepsilon}_{Nt} \end{pmatrix}$$

and

$$\mathbf{G} = \begin{pmatrix} \mathbf{A}_0 \mathbf{W}_0 \\ \mathbf{A}_1 \mathbf{W}_1 \\ \vdots \\ \mathbf{A}_N \mathbf{W}_N \end{pmatrix}, \mathbf{H} = \begin{pmatrix} \mathbf{B}_0 \mathbf{W}_0 \\ \mathbf{B}_1 \mathbf{W}_1 \\ \vdots \\ \mathbf{B}_N \mathbf{W}_N \end{pmatrix}$$

It can be commented that $\mathbf{G}$ is a $k \times k$ -dimensional matrix and in general will be full of rank and hence non-singular. Thus, the GVAR model in all of the variables can be written as;

$$\mathbf{x}_t = \mathbf{G}^{-1}\mathbf{a}_0 + \mathbf{G}^{-1}\mathbf{a}_{1t} + \mathbf{G}^{-1}\mathbf{H}\mathbf{x}_{t-1} + \mathbf{G}^{-1}\boldsymbol{\varepsilon}_t \quad (11)$$

Which may be solved recursively forward to obtain the values of $\mathbf{x}_t$.

In this study, this solution may be adopted to 19 countries with 7 domestic and foreign variables. For instance;

$$\mathbf{x}_t = \begin{pmatrix} \mathbf{x}_{1t} \\ \mathbf{x}_{2t} \\ \vdots \\ \mathbf{x}_{19,t} \end{pmatrix} = \begin{pmatrix} L_{1t} \\ S_{1t} \\ C_{1t} \\ INDPRO_{1t} \\ INFRA_{1t} \\ POLRA_{1t} \\ STOCK_{1t} \\ L_{2t} \\ S_{2t} \\ C_{2t} \\ INDPRO_{2t} \\ INFRA_{2t} \\ POLRA_{2t} \\ STOCK_{2t} \\ \vdots \\ L_{19,t} \\ S_{19,t} \\ C_{19,t} \\ INDPRO_{19,t} \\ INFRA_{19,t} \\ POLRA_{19,t} \\ STOCK_{19,t} \end{pmatrix}, \mathbf{z}_{1t} = \begin{pmatrix} L_{1t} \\ S_{1t} \\ C_{1t} \\ INDPRO_{1t} \\ INFRA_{1t} \\ POLRA_{1t} \\ STOCK_{1t} \\ L_{1t}^* \\ S_{1t}^* \\ C_{1t}^* \\ INDPRO_{1t}^* \\ INFRA_{1t}^* \\ POLRA_{1t}^* \\ STOCK_{1t}^* \end{pmatrix}, \mathbf{z}_{it} = \begin{pmatrix} L_{it} \\ S_{it} \\ C_{it} \\ INDPRO_{it} \\ INFRA_{it} \\ POLRA_{it} \\ STOCK_{it} \\ L_{it}^* \\ S_{it}^* \\ C_{it}^* \\ INDPRO_{it}^* \\ INFRA_{it}^* \\ POLRA_{it}^* \\ STOCK_{it}^* \end{pmatrix}, i=1, \dots, 19.$$

Using the trade shares, denoted simply by w_{ij} , to construct the foreign variables, the link matrices for 19 countries are;

$$\begin{aligned}
\mathbf{W}_1 &= \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & w_{1,2} & 0 & 0 & w_{1,3} & 0 & 0 & \cdots & w_{1,19} & 0 & 0 \\ 0 & 0 & 0 & 0 & \ddots & 0 & 0 & \ddots & 0 & \cdots & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{1,2} & 0 & 0 & w_{1,3} & \cdots & 0 & 0 & w_{1,19} \end{pmatrix} \\
&= \begin{pmatrix} \mathbf{I}_{19} & 0 & 0 & \cdots & 0 \\ 0 & w_{1,2}\mathbf{I}_{19} & w_{1,3}\mathbf{I}_{19} & \cdots & w_{1,19}\mathbf{I}_{19} \end{pmatrix} \\
\mathbf{W}_2 &= \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \ddots & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ w_{2,1} & 0 & 0 & 0 & 0 & 0 & w_{2,3} & 0 & 0 & \cdots & w_{2,19} & 0 & 0 \\ 0 & \ddots & 0 & 0 & 0 & 0 & 0 & \ddots & 0 & \cdots & 0 & \ddots & 0 \\ 0 & 0 & w_{2,1} & 0 & 0 & 0 & 0 & 0 & w_{2,3} & \cdots & 0 & 0 & w_{2,19} \end{pmatrix} \\
&= \begin{pmatrix} 0 & \mathbf{I}_{19} & 0 & \cdots & 0 \\ w_{2,1}\mathbf{I}_{19} & 0 & w_{2,3}\mathbf{I}_{19} & \cdots & w_{2,19}\mathbf{I}_{19} \end{pmatrix} \\
&\vdots \\
\mathbf{W}_{19} &= \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 & 1 \\ w_{19,1} & 0 & 0 & w_{19,2} & 0 & 0 & \cdots & w_{19,18} & 0 & 0 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 & \ddots & 0 & \cdots & 0 & \ddots & 0 & 0 & 0 & 0 \\ 0 & 0 & w_{19,1} & 0 & 0 & w_{19,2} & \cdots & 0 & 0 & w_{19,18} & 0 & 0 & 0 \end{pmatrix} \\
&= \begin{pmatrix} 0 & 0 & \cdots & 0 & \mathbf{I}_{19} \\ w_{19,1}\mathbf{I}_{19} & w_{19,2}\mathbf{I}_{19} & \cdots & w_{19,18}\mathbf{I}_{19} & 0 \end{pmatrix}
\end{aligned}$$

Recall that $\mathbf{W}_1 \mathbf{x}_t = \mathbf{z}_{1t}$. Each variable (L, S, C, INDPRO, INFRA, POLRA, STOCK) in matrix must be multiply with trade weights. In matrices, two example is as follows:

$$\mathbf{z}_{1t} = \begin{pmatrix} L_{1t} \\ S_{1t} \\ C_{1t} \\ INDPRO_{1t} \\ INFRA_{1t} \\ POLRA_{1t} \\ STOCK_{1t} \\ w_{1,2}^L L_{1t}^* \\ w_{1,2}^S S_{1t}^* \\ w_{1,2}^C C_{1t}^* \\ w_{1,2}^{INDPRO} INDPRO_{1t}^* \\ w_{1,2}^{INFRA} INFRA_{1t}^* \\ w_{1,2}^{POLRA} POLRA_{1t}^* \\ w_{1,2}^{STOCK} STOCK_{1t}^* \end{pmatrix}, \mathbf{z}_{2t} = \begin{pmatrix} L_{2t} \\ S_{2t} \\ C_{2t} \\ INDPRO_{2t} \\ INFRA_{2t} \\ POLRA_{2t} \\ STOCK_{2t} \\ w_{2,1}^L L_{2t}^* \\ w_{2,1}^S S_{2t}^* \\ w_{2,1}^C C_{2t}^* \\ w_{2,1}^{INDPRO} INDPRO_{2t}^* \\ w_{2,1}^{INFRA} INFRA_{2t}^* \\ w_{2,1}^{POLRA} POLRA_{2t}^* \\ w_{2,1}^{STOCK} STOCK_{2t}^* \end{pmatrix}, \dots, \mathbf{z}_{19t}$$

Note that the country specific weights are non-negative and satisfy the adding-up restrictions $w_{1,2} + w_{1,3} + \dots + w_{1,19} = 1$, $w_{1,1} + w_{2,3} + \dots + w_{2,19} = 1$, $\dots$, $w_{19,1} + w_{19,2} + \dots + w_{19,18} = 1$.

$$\mathbf{a}_1 = \begin{pmatrix} \mathbf{a}_{1,1} \\ \mathbf{a}_{1,2} \\ \vdots \\ \mathbf{a}_{1,19} \end{pmatrix}, \mathbf{a}_2 = \begin{pmatrix} \mathbf{a}_{2,1} \\ \mathbf{a}_{2,2} \\ \vdots \\ \mathbf{a}_{2,19} \end{pmatrix}, \boldsymbol{\varepsilon}_t = \begin{pmatrix} \boldsymbol{\varepsilon}_{1,t} \\ \boldsymbol{\varepsilon}_{2,t} \\ \vdots \\ \boldsymbol{\varepsilon}_{19,t} \end{pmatrix}$$

and recalling $\mathbf{G} = \mathbf{A}_i \mathbf{W}_i$, $\mathbf{H} = \mathbf{B}_i \mathbf{W}_i$;

$$\mathbf{G} = \begin{pmatrix} \mathbf{A}_1 \mathbf{W}_1 \\ \mathbf{A}_2 \mathbf{W}_2 \\ \vdots \\ \mathbf{A}_{19} \mathbf{W}_{19} \end{pmatrix}, \mathbf{H} = \begin{pmatrix} \mathbf{B}_1 \mathbf{W}_1 \\ \mathbf{B}_2 \mathbf{W}_2 \\ \vdots \\ \mathbf{B}_{19} \mathbf{W}_{19} \end{pmatrix}$$

Finally,

$$\mathbf{A}_1 = (\mathbf{I}_3, -\boldsymbol{\Lambda}_{1,1}), \mathbf{A}_2 = (\mathbf{I}_3, -\boldsymbol{\Lambda}_{2,1}), \dots, \mathbf{A}_{19} = (\mathbf{I}_3, -\boldsymbol{\Lambda}_{19,1})$$

where $\mathbf{I}_s$ is an identity matrix of order s . Using the foregoing $\mathbf{W}_i$ and $\mathbf{A}_i$ matrices, the $\mathbf{G}$ matrix defined in equation (10) can be constructed. $\mathbf{G}$ is an 19×19 matrix and must be non-singular due to the global model is complete. If a model is complete, then it is possible to find a unique solution for all its endogenous variables. Since all constants are defined and it requires too many iterative processing steps, equation (11) can now be solved using a suitable programming.

By weighting the foreign variables with trade and simplifying the GVAR model, the coefficients of the model can be obtained through a standard VAR solution (recursively forward solution for equation (11)). At this point, the decision to be made is determining the number of lags should be used in the solution. According to the Akaike Information Criterion, the GVAR toolbox proposed to use 2 lags for all variables.

3.2.3. Impulse and Response Analysis

Impulse-Response Functions (IRFs) are key tools in time series analysis, particularly when examining the effects of shocks on a system of variables over time. Impulse response analysis examines how specific shocks affect the future states of a dynamic system and, consequently, all the variables in the model (Gujarati, 2004). The IRFs provide a way to analyse how a system responds to a shock in one of its variables. There are several types of impulse-response functions based on different modelling approaches (Enders, 2014):

1. Orthogonalized Impulse-Response Functions (OIRFs); are obtained after applying a Cholesky decomposition to the residuals of a VAR model, making the error terms orthogonal (uncorrelated) to each other. They are used in a Vector Autoregressive (VAR) model where the ordering of variables is important. The Cholesky decomposition ensures that the impulse-response analysis isolates the effect of a shock to a particular variable, with the assumption that each variable is only contemporaneously affected by the variables that precede it in the ordering. The OIRF shows the dynamic response of one variable to a shock, assuming that the other variables do not react contemporaneously.
2. Generalized Impulse-Response Functions (GIRFs); are a generalization of orthogonalized IRFs, designed to avoid the dependency on variable ordering in a VAR model. GIRFs are used when the results are not intended to have dependency on the specific ordering of the variables in the model. GIRFs provide a more flexible approach than OIRFs because they do not rely on the Cholesky decomposition. For instance, a generalized IRF shows how a shock to one variable impacts all variables in the system, taking into account the interdependencies between them without the need to impose a specific variable ordering.

3. Structural Impulse-Response Functions (SIRFs); are computed based on a structural model, where the relationships between the variables are derived from theory or imposed restrictions. SIRFs are mostly used in models where the causal relationships are explicitly modelled, like in a Structural Vector Autoregressive (SVAR) model. They give insights into how a shock to one variable (such as a policy intervention or an external shock) impacts the entire system over time, considering the structural (theoretical) relationships between the variables.

Since GIRFs do not require imposing any variable ordering on the model and such an ordering would not be feasible in a multi-country setting, they align well with the aims of this study. Therefore, the effects of shocks applied to yield curve factors on the indicators of other countries will be examined by using generalized impulse-response functions in this study. The impulse responses of the shocks to particular variables in the GVAR model are represented by the generalized impulse response functions (GIRFs), which were first introduced by Koop, Pesaran, and Potter (1996) and later adapted to VAR models by Pesaran and Shin (1998). According to their mathematical expressions, the definition of GIRFs is based on:

$$GIRF(x_t; u_{ilt}, n) = E(x_{t+n} | u_{ilt} = \sqrt{\sigma_{ii,ll}}, I_{t-1}) - E(x_{t+n} | I_{t-1})$$

where I_{t-1} is the information set at time $t - 1$, $\sigma_{ii,ll}$ is the diagonal element of the variance-covariance matrix Σ_u corresponding to the l^{th} equation in the i^{th} country, and n is the horizon. On the assumption that u_t has a multivariate normal distribution, it follows that GIRFs of a unit (one standard error) shock at time t to the l^{th} equation in the GVAR model on the j^{th} variable at time $t + n$ is given by the j^{th} element of:

$$GIRF(x_t; u_{lt}, n) = \frac{e_j' A_n G_0^{-1} \Sigma_u e_l}{\sqrt{e_l' \Sigma_u e_l}}, n = 0, 1, 2, \dots; l, j = 1, 2, \dots, k$$

where $e_l = (0, 0, \dots, 0, 1, 0, \dots, 0)'$ is a selection vector with unity as the l^{th} element in the case of a country-specific shock. The A_n matrices are calculated based on structure of shocks⁵ and the G_0^{-1} is the coefficient matrix that the shocks are reflected through the

⁵ Calculated as recursively $A_n = F_1 A_{n-1} + F_2 A_{n-2} + \dots + F_p A_{n-p}$, $n=1, 2, \dots$, with $A_0 = I_m$, $A_n = 0$, for $n < 0$.

other variables. While GIRFs are invariant to the ordering of the variables, it is required to be cautious when interpretating the effect of shocks using GIRFs as they allow correlation of the error terms (the error terms are not orthogonal) (di Mauro and Pesaran, 2013).

CHAPTER 4

EMPIRICAL FINDINGS

This chapter analyses the empirical results. It investigates the characteristics of Türkiye's yield curve in response to shocks from domestic and foreign indicators, thereby also examining the effectiveness of economic policies implemented in Türkiye on the yield curve.

The main findings in this chapter are, first, Generalized Impulse-Response Functions (GIRFs) with confidence intervals⁶ derived from the results of the GVAR analysis. The analysis examines how a one standard deviation shock (impulse) applied to the variables included in the model changes (responses) other variables in direction and magnitude. To ensure consistency in interpreting the findings, the results are classified as *minor*, *medium*, and *major* effects. *Minor* effects reflect responses equal to or less than 0.5 s.d., *medium* effects encompass responses between 0.5 and 1 s.d., and *major* effects indicate responses greater than 1 s.d. Within this classification framework, all impulse-response functions illustrated in the chapter start from 0 and are scaled in increments of 0.5 in both positive and negative directions. This is intended to facilitate the understanding of the graphs. For the findings to be interpreted in an understandable manner, major and medium responding results have been considered significant within the classification framework and are discussed in the main body of the thesis with an economic interpretation. Provided confidence intervals quantify the uncertainty surrounding estimates in impulse response functions and help assess whether observed effects are statistically significant or merely the result of random variation. They are essential for interpreting model results reliably and testing statistical significance. At the end of the section, secondly, an OIRF analysis is conducted to assess the reliability of the findings obtained from the GIRF analysis as well. The OIRF analysis, presented with confidence intervals, is carried out by considering the results at the GIRF analysis that generated medium and large responses.

⁶ The dotted lines in the figures, along with the corresponding colour scheme, represent the confidence intervals of the estimated GIRF and OIRF series.

4.1. SOLUTION OF GVAR MODEL AND UNIT ROOT TESTS WITH PROGRAMMING

While estimating the yield curves for each country, R programming language is used. A coding package called as “*YieldCurve*” library that is created by Consiglio and Guirrerri (2011) is defined to the R programming. Together with necessary adjustments on coding that is required for the study, each country’s bond set are imported to the R. The obtained yield curve parameters are then exported to the separate excel sheets. Due to the difference in interpretation of slope factor expressed previously, the sign of results has changed with minus.

GVAR Modelling has been solved by using GVAR Toolbox 2.0 which is Excel-based MatLab procedure developed by Smith (2014). Since the system allows to see ADF unit root t-statistics results, the only two criteria can be used in program which are Akaike Information Criterion (AIC) and Schwarz-Bayesian Criteria (SBC). To increase the number of tests performed, E-Views package programming has been used. In determining whether the series contain a unit root, the number of tests (ADF, PP, ERSPO, NG-Perron) that fail to reject the null hypothesis (i.e., the presence of a unit root) is taken into account. These series are shown with stars near the country abbreviation (Table 3, Table 4 and Table 5).

Table 3. Unit Root Test Statistics and Confidence Levels

Unit Root Tests (*** 1%, ** 5%, * 10% are significance levels)		Augmented Dickey Fuller (ADF)			Phillips-Perron (PP) Test	Elliott-Rothenberg-Stock Point Optimal (ERSPO)	NG-Perron
		Akaike Info Criterion	Schwarz Info Criterion	Hannan-Quinn Criterion	Bartlett kernel	AR spectral OLS	AR GLS-detrended
LEVEL (lvl)	bra	-2.276493	-3.721450***	-2.977425**	-5.165235***	1.535205***	-11.7049**
	bul*	-0.956830	-1.998134	-1.998134	-5.801650***	7.924470	-3.21795
	chl	-8.738971***	-8.738971***	-8.738971***	-8.723570***	2.175589**	-4.15813
	chi	-4.416220***	-4.416220***	-4.416220***	-7.178326***	1.218096***	-21.2378***
	col	-3.908338***	-3.908338***	-3.908338***	-3.896430***	1.163812***	-22.8711***
	hun	-1.462246	-4.232119***	-2.421934	-4.038501***	0.920803***	-27.2068***
	ind	-3.838536***	-4.090291***	-4.322140***	-4.028527***	1.025451***	-29.0117***
	indo	-2.518631	-3.633343***	-2.883041**	-4.309244***	2.332935**	-5.72554
	mal	-4.059142***	-4.531414***	-4.531414***	-4.589349***	1.628525***	-18.6513***
	mex	-2.953927**	-2.953927**	-2.953927**	-4.890483***	1.336210***	-18.2023***
	pol*	-1.600585	-1.800336	-1.800336	-2.351859	5.242157	-5.15649
	rom	-3.036910**	-5.902722***	-5.902722***	-7.840334***	1.524710***	-2.10561
	rus	-4.231928***	-4.231928***	-4.231928***	-6.747473***	1.354632***	-17.9050***
	saf	-2.845867*	-10.80846***	-2.845867*	-10.63625***	0.418230***	-80.0231***
	sko*	-1.917909	-2.175134	-1.917909	-4.166057***	13.66297	-1.70236
	tha*	-3.275538**	-1.705414	-1.705414	-7.109541***	5.765028	-4.14313
	tur	-3.206524**	-3.485491***	-3.206524**	-4.185376***	2.260591**	-9.81422**
	us*	-0.548017	-2.391037	-2.391037	-2.917231**	6.303436	-4.69616
	vie	-1.177563	-4.685483***	-1.177563	-4.461168***	0.967055***	-33.9182***

Table 4. Unit Root Test Statistics and Confidence Levels (cont.)

SLOPE (slp)	bra	-4.051168***	-5.343199***	-5.343199***	-5.072006***	0.782608***	-35.8691***
	bul	-5.606466***	-9.069205***	-9.069205***	-9.170594***	1.293492***	-9.66452**
	chl	-3.884612***	-5.681713***	-3.884612***	-8.901237***	2.332239**	-4.24457
	chi	-2.636605*	-6.306901***	-6.306901***	-8.865660***	0.251064***	-31.1125***
	col	-2.878840**	-2.878840**	-2.878840**	-2.871535*	2.789746**	-13.0755**
	hun	-6.287089***	-8.625148***	-6.287089***	-8.745054***	1.157752***	-9.37730**
	ind	-4.006430***	-4.006430***	-4.006430***	-5.506871***	0.909331***	-26.8804***
	indo	-1.354512	-6.387872***	-6.387872***	-8.984495***	0.443340***	-56.7475***
	mal	-4.395176***	-3.537869***	-3.537869***	-4.287927***	1.285614***	-20.6910***
	mex*	-2.529729	-2.529729	-2.529729	-2.408953	5.638796	-4.88663
	pol	-4.005499***	-4.005499***	-4.005499***	-4.891500***	3.763114*	-7.61647**
	rom	-2.179559	-2.537020	-2.232234	-5.000313***	2.776293**	-5.63492*
	rus	-3.975759***	-8.873270***	-3.975759***	-9.131014***	0.519825***	-19.5425***
	saf	-3.127469**	-4.504916***	-3.127469**	-4.483633***	0.917257***	-29.8709***
	sko	-2.191873	-2.598545*	-2.749650*	-10.36329***	19.28653	-0.87273
	tha	-3.740287***	-3.740287***	-3.740287***	-6.432729***	1.000717***	-26.4423***
	tur	-2.727628*	-2.685937*	-2.685937*	-2.855638*	2.236553**	-12.2497**
	us*	-1.673793	-1.673793	-1.673793	-2.196244	4.188994*	-5.88244*
	vie	-2.968832***	-5.563790***	-2.968832***	-5.581353***	0.787963***	-36.1730***
CURVATURE (curv)	bra	-7.160507***	-7.160507***	-7.160507***	-7.070866***	0.698728***	-34.1505***
	bul	-2.487946	-7.586661***	-3.094682**	-12.84222*	2.758160**	-0.30410
	chl	-5.689617***	-8.554716***	-8.554716***	-8.538243***	1.409728***	-6.47061*
	chi	-6.911840***	-6.911840***	-6.911840***	-7.227042***	0.433466***	-56.8563***
	col	-2.664158*	-4.717021***	-4.717021***	-4.502301***	4.861372	-6.83098*
	hun	-3.496245***	-4.381818***	-3.496245***	-6.872839***	0.916713***	-27.3646***
	ind	-4.170552***	-4.170552***	-4.170552***	-5.626859***	1.068233***	-26.9104***
	indo	-8.219552***	-8.219552***	-8.219552***	-8.093835***	0.972972***	-6.02377*
	mal	-4.998365***	-5.611084***	-4.509204***	-5.452397***	0.728256***	-27.5178***
	mex	-3.936849***	-5.619844***	-5.619844***	-8.887563***	0.560473***	-43.8433***
	pol	-4.403864***	-4.403864***	-4.403864***	-5.099855***	3.895260*	-7.21009*
	rom	-1.711677	-4.542832***	-1.891645	-6.514545***	1.400968***	-6.58369*
	rus	-6.375049***	-6.375049***	-6.375049***	-6.432613***	0.470870***	-52.3638***
	saf	-2.709191*	-6.394876***	-3.897900***	-6.511119***	0.496004***	-53.1483***
	sko	-2.338019	-5.316720***	-2.338019	-13.73925***	1.455622***	-12.1888**
	tha	-10.13995***	-10.13995***	-10.13995***	-10.29379***	0.355247***	-78.7245***
	tur	-2.665039*	-2.404114	-2.404114	-2.656201*	2.046870**	-13.1999**
	us	-2.364009	-3.404848**	-2.364009	-3.280250**	1.512506***	-13.8585***
	vie	-2.822939**	-8.450682***	-8.450682***	-8.574312***	0.566242***	-34.4423***
INDUSTRIAL PRODUCTION (indpro)	bra	-8.818852***	-8.818852***	-12.13991***	-12.36123***	0.367549***	-79.5769***
	bul	-3.383257**	-14.60478***	-14.60478***	-14.58408***	0.623445***	-1.30946
	chl	-6.608694***	-10.33519***	-10.33519***	-22.42413***	0.087643***	-79.5626***
	chi	-9.017787***	-14.56311***	-9.017787***	-14.05063***	0.121411***	-55.2590***
	col	-2.369372	-12.10834***	-2.369372	-17.27148***	0.331930***	0.17933
	hun	-9.243127***	-10.48446***	-9.243127***	-13.85079***	0.238117***	-83.3162***
	ind	-10.56671***	-12.92951***	-10.56671***	-20.14116***	0.160878***	-146.680***
	indo	-5.390468***	-13.66634***	-13.66634***	-25.68997***	0.207768***	-117.276***
	mal	-8.670379***	-13.77475***	-8.670379***	-19.16047***	0.192926***	-1.02507
	mex	-8.440008***	-11.86661***	-11.86661***	-13.63996***	0.166411***	-144.854***
	pol	-7.299815***	-9.419916***	-9.419916***	-14.03241***	0.199645***	-12.3849**
	rom	-9.595757***	-11.35519***	-9.595757***	-16.92019***	0.229923***	-83.4058***
	rus	-9.219866***	-12.06873***	-9.219866***	-12.05735***	0.493634***	-8.62533**
	saf	-10.04046***	-12.20134***	-10.04046***	-17.61274***	0.189530***	-127.890***
	sko	-5.676884***	-12.99606***	-12.99606***	-13.02463***	0.758796***	-3.52109
	tha	-8.923656***	-8.923656***	-8.923656***	-15.66237***	0.000328***	-81.7091***
	tur	-9.132124***	-13.51194***	-9.132124***	-14.23211***	0.342984***	-83.3621***
	us	-10.35019***	-10.35019***	-10.35019***	-9.888828***	0.186078***	-127.012***
	vie	-12.71883***	-12.71883***	-12.71883***	-18.89216***	0.211791***	-115.436***

Table 5. Unit Root Test Statistics and Confidence Levels (cont.)

POLICY RATE (polra)	bra	-3.520947***	-3.520947***	-3.520947***	-1.744155	0.486140***	-54.8524***
	bul	-6.499338***	-6.499338***	-6.499338***	-3.019479**	7027.881	0.56135
	chl	-3.432419**	-3.069564**	-3.432419**	-2.538690	3.938761*	-7.77612*
	chi*	-2.070430	-2.117766	-2.117766	-1.891956	37.85395	-0.02049
	col	-4.138067***	-4.138067***	-4.138067***	-2.418443	6.829967	-6.47968*
	hun*	-1.853383	-1.853383	-1.853383	-1.341910	52.67599	-0.48241
	ind*	-1.991937	-1.977691	-1.991937	-1.325874	5.748673	-5.65883*
	indo*	-1.545105	-1.257201	-1.545105	-1.241143	18.52957	-0.49240
	mal*	-1.952986	-1.952986	-1.952986	-1.511770	7.992359	-3.53863
	mex	-2.599838*	-2.599838*	-2.599838*	-1.889042	3.887855*	-7.65532*
	pol*	-2.246023	-2.246023	-2.246023	-1.720868	24.20373	-1.00577
	rom*	-2.490193	-2.095416	-2.095416	-1.121381	130.7515	0.09799
	rus	-2.277000	-2.630564*	-2.630564*	-2.355768	2.420406**	-10.8465**
	saf	-3.094323**	-3.292192**	-3.094323**	-2.099674	24.68307	-0.95633
	sko	-3.015426**	-2.751309*	-2.751309*	-2.597051*	117.1901	0.53510
	tha*	-2.420176	-1.899001	-2.047949	-1.743266	15.54533	-1.25830
INFLATION RATE (infra)	tur	-3.204141**	-3.204141**	-3.204141**	-2.292103	1.632554***	-14.0880***
	us	-3.034593**	-3.034593**	-3.034593**	-3.049712**	54.79985	-0.04631
	vie	-2.593325*	-2.139394	-2.432898	-1.987345	2.605990**	-9.89436**
	bra	-2.607212*	-6.839465***	-5.119426***	-7.140830***	0.462877***	-56.3555***
	bul	-7.506060***	-7.506060***	-7.506060***	-7.479641***	1.029360***	-5.97289*
	chl	-3.643479***	-8.549926***	-8.549926***	-9.042884***	0.858152***	-10.3933**
	chi	-4.517790***	-10.00701***	-10.00701***	-10.07340***	0.495654***	-75.2799***
	col	-3.569545***	-7.057631***	-5.389563**	-7.273096***	1.171002***	-6.23319*
	hun	-2.163653	-8.454207***	-6.064084***	-8.544782***	0.485854***	-37.2261***
	ind	-2.905082**	-10.25391***	-10.25391***	-10.23056***	0.315585***	-78.8553***
	indo	-4.567185***	-8.389513***	-7.732814***	-8.233635***	1.558016***	-2.94327
	mal	-8.800463***	-8.800463***	-8.800463***	-8.689258***	0.244399***	-72.2988***
	mex	-3.164071**	-9.664764***	-9.664764***	-9.616118***	0.321160***	-76.6479***
	pol	-0.328939	-4.298622***	-4.298622***	-6.787340***	1.429757***	-24.6834***
	rom	-2.366048	-6.549440***	-6.549440***	-10.97065***	0.642568***	-37.9259***
	rus	-5.302850***	-5.302850***	-5.302850***	-4.573465***	1.257838***	-17.5408***
STOCK INDEX CHANGE (stock)	saf	-7.831720***	-9.195843***	-9.195843***	-9.195843***	2.570745**	-1.47517
	sko	-10.16954***	-10.16954***	-10.16954***	-10.13275***	0.355365***	-76.0757***
	tha	-4.394643***	-10.44203***	-8.165040***	-10.31974***	1.187699***	-4.55204
	tur	-0.121960	-3.688415***	-1.440626	-3.789713***	4.843290	-52.8376***
	us	-4.917277***	-6.509184***	-4.917277***	-6.246387***	0.669631***	-33.1923***
	vie	-5.047941***	-5.047941***	-5.047941***	-4.829236***	3.334661*	-11.6526**
	bra	-9.381347***	-10.93755***	-9.381347***	-10.86722***	0.632271***	-16.4751***
	bul	-4.758445***	-9.261178***	-7.442775***	-9.459192***	2.675810**	-2.58284
	chl	-13.10472***	-13.10472***	-13.10472***	-13.10319***	1.051154***	-4.28894
	chi	-11.93334***	-11.93334***	-11.93334***	-11.98954***	1.758104***	-3.18270
	col	-8.533452***	-12.01098***	-12.01098***	-12.00938***	1.766741***	-3.97874
	hun	-10.60511***	-10.60511***	-10.60511***	-10.62594***	1.063402***	-7.35542*
	ind	-12.41195***	-12.41195***	-12.41195***	-12.42652***	1.554651***	-3.48114
	indo	-9.955503***	-9.955503***	-9.955503***	-10.02180***	0.527180***	-24.5281***
	mal	-11.49700***	-11.49700***	-11.49700***	-11.56034***	0.689833***	-6.40013*
	mex	-12.00439***	-12.00439***	-12.00439***	-12.03617***	0.528823***	-79.8107***
	pol	-9.448660***	-9.448660***	-9.448660***	-11.57751***	1.603497***	-2.61878
	rom	-7.939032***	-8.808096***	-8.808096***	-10.06454***	2.740944**	-1.75807
	rus	-5.909228***	-10.16288***	-10.16288***	-10.28946***	2.060877**	-4.79519
	saf	-14.06570***	-14.06570***	-14.06570***	-14.01667***	0.901279***	-7.85301*
	sko	-6.640337***	-12.64351***	-12.64351***	-12.65491***	2.708833**	-1.68362
	tha	-10.98241***	-10.98241***	-10.98241***	-11.04205***	1.082112***	-6.50622*
	tur	-5.278208***	-13.07117***	-13.07117***	-13.10020***	2.897891**	-0.87139
	us	-5.534724***	-12.12843***	-9.599075***	-12.13025***	0.978420***	-6.11660*
	vie	-10.38126***	-10.38126***	-10.38126***	-10.33118***	0.706556***	-11.0870**

Note: Stars (*, **, ***) reject the initial hypothesis which is accepting that time series include unit root according to ADF, PP, ERSPO and NG-Perron tests within 10%, 5% and 1% significance levels respectively.

Source: Author's calculations via E-Views

According to the test results, level factors of yield curves of Bulgaria, Poland, South Korea, Thailand, and the U.S., slope factors yield curves of Mexico and the U.S., policy rate of China, Hungary, India, Indonesia, Malaysia, Poland, Romania and Thailand have unit root. Hodrick-Prescott (HP) filtering, which is a special case of the Kalman filtering technique, is used to make the series with unit root stationary (Diebold et al., 2008, Kaya, 2017). While detrended levels are shown in Figure 3, detrended slopes are in Figure 4. Policy rates which also include unit root detrended and showed in Figure 5. The figures display the series after detrending. The detrended series were subsequently re-tested to examine whether they contain a unit root.

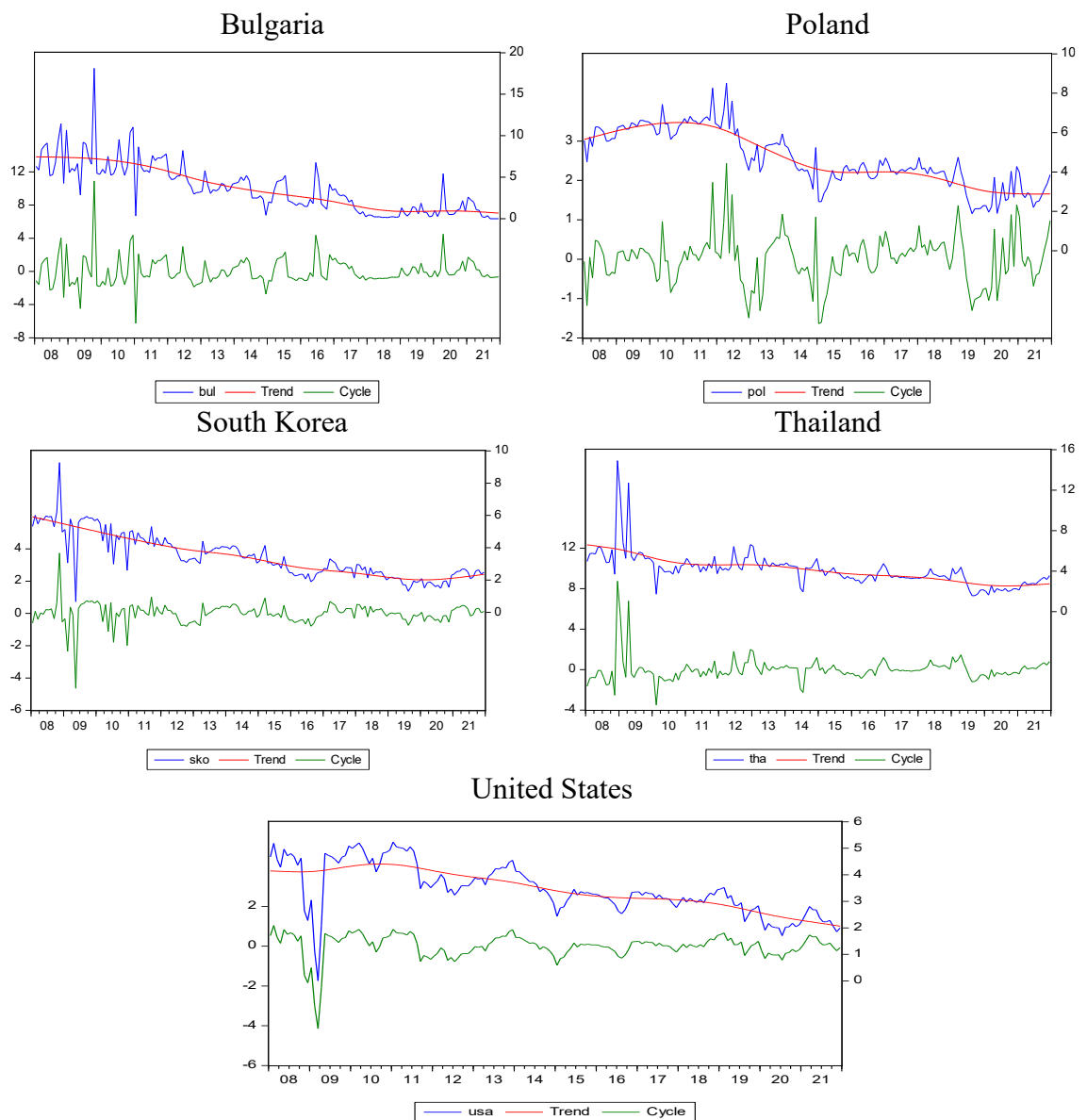


Figure 3. HP-Filter Detrending Results for Levels

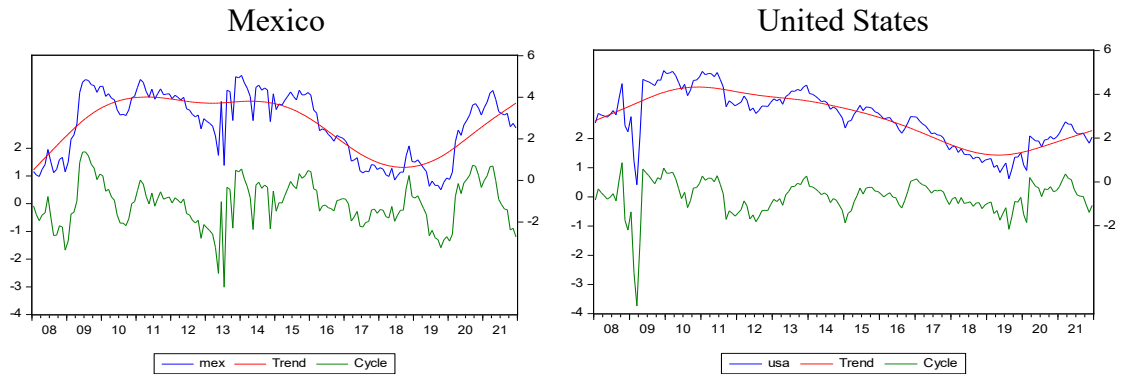


Figure 4. HP-Filter Detrending Results for Slopes

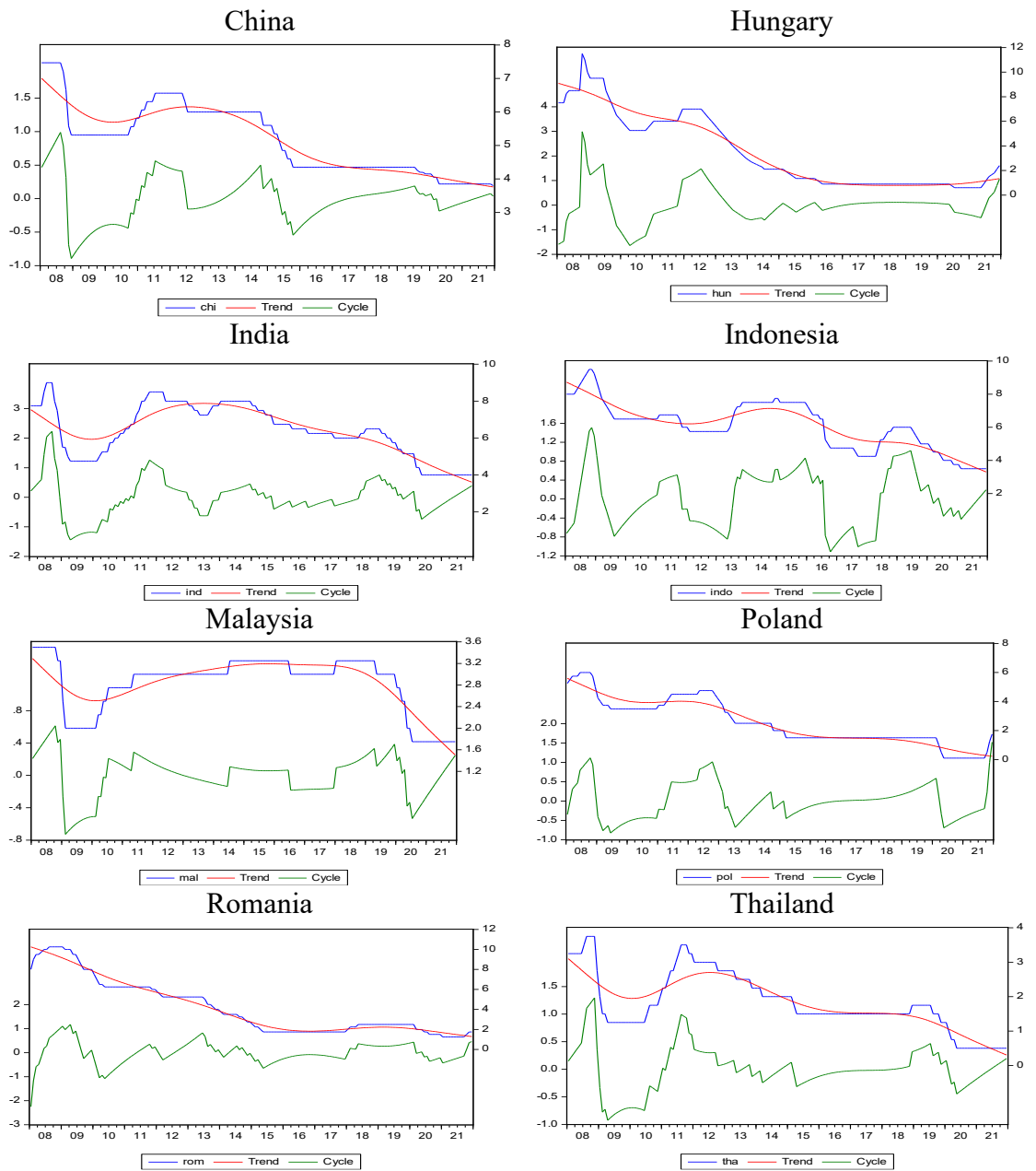


Figure 5. HP-Filter Detrending Results for Policy Rates

4.2. INTERACTIONS BETWEEN THE YIELD CURVE FACTORS

The results of the GVAR estimation and GIRF analysis with confidence intervals reveal that the factors of the yield curve in Türkiye are highly sensitive to each other. The level and slope of the yield curve respond positively to each other. While the level initially gives a high response to an impact from the slope, the response continues to develop on the level after the first month, as much as the impact (Figure 6). It has been observed that the increase in the slope (the rise of long-term interest rates relative to short-term rates) has also raised the level during the analysed period. Accordingly, an examination of the effect of slope on the level indicates that both factors move in tandem, influencing each other positively and in a one-to-one ratio.

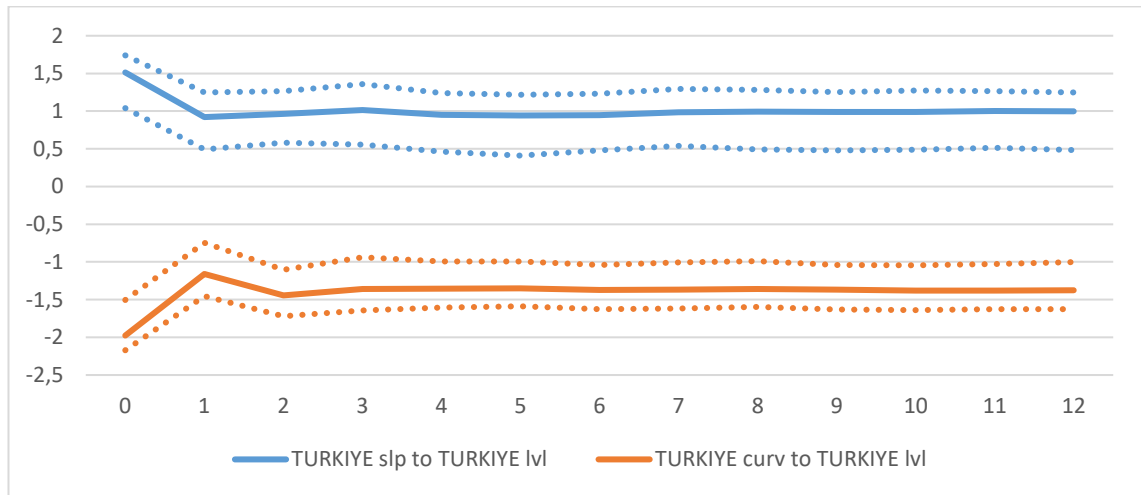


Figure 6. Response of Türkiye's Level to Türkiye's Slope and Curvature

Similarly, an increase in the level of the risk-free interest rate also increases the slope of the yield curve (Figure 7). When viewed within the framework of economic reasoning, an increase in long-term fixed interest rates will have a contracting/cooling effect on the economy's long-term equilibrium. This situation also influences the slope of the yield curve in an increasing direction. An increase in the slope reflects the expectation that long-term interest rates will be higher than short-term rates in the long run.

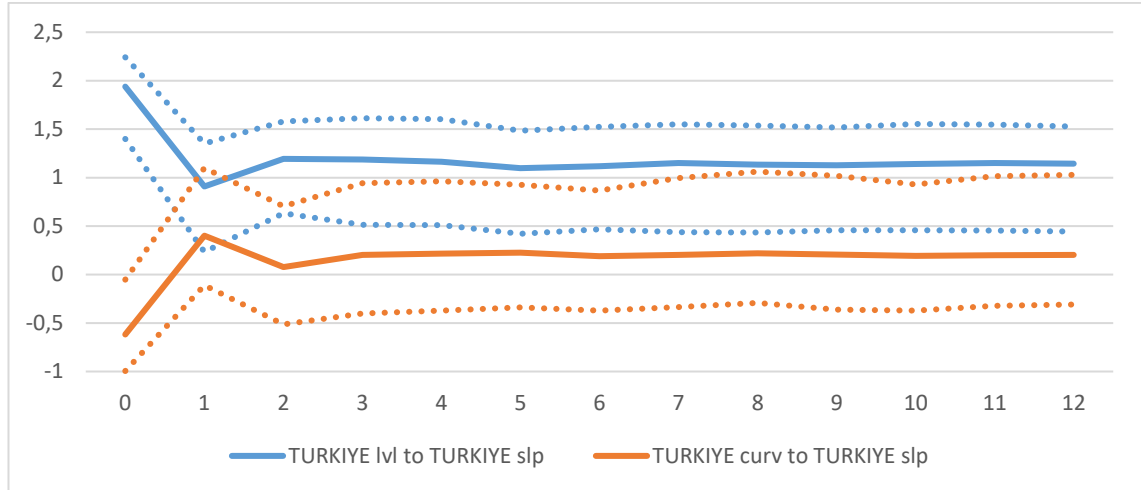


Figure 7. Response of Türkiye's Slope to Türkiye's Level and Curvature

It is clearly observed that, in Türkiye, there exists a bidirectional relationship between the level and the slope of the yield curve. This relationship is also statistically significant. Furthermore, the fact that both the upper and lower bounds of the confidence intervals remain in the positive domain reinforces the strength of this significant relationship and supports the conclusion that it is not random.

Although the relationship between the curvature and macroeconomic indicators is defined as uncertain in the literature, its relationship with other yield curve factors stands out. As seen in Figure 6, Figure 7 and Figure 8, it is observed that the curvature has bidirected and very strong relationship with level. Since the curvature reflects the fluctuations in the yield curve, its relationship with other factors is worth examining. Accordingly, during the period under review, the curvature of Türkiye's yield curve responds negatively to the impact from the level (Figure 8). Moreover, it responds in a range of 5.5-6 units for every 1 unit of shock. From an economic reasoning perspective, it can be interpreted that an increase in the long-term constant interest rate (the level) has a strong ability to significantly change the yield curve. In contrast, the relationship between the slope and the curvature appears to be considerably weaker (Figure 8). Moreover, when evaluated alongside the confidence intervals, it becomes evident that the relationship between the slope and curvature may be random and not statistically significant (Figure 7 and Figure 8).

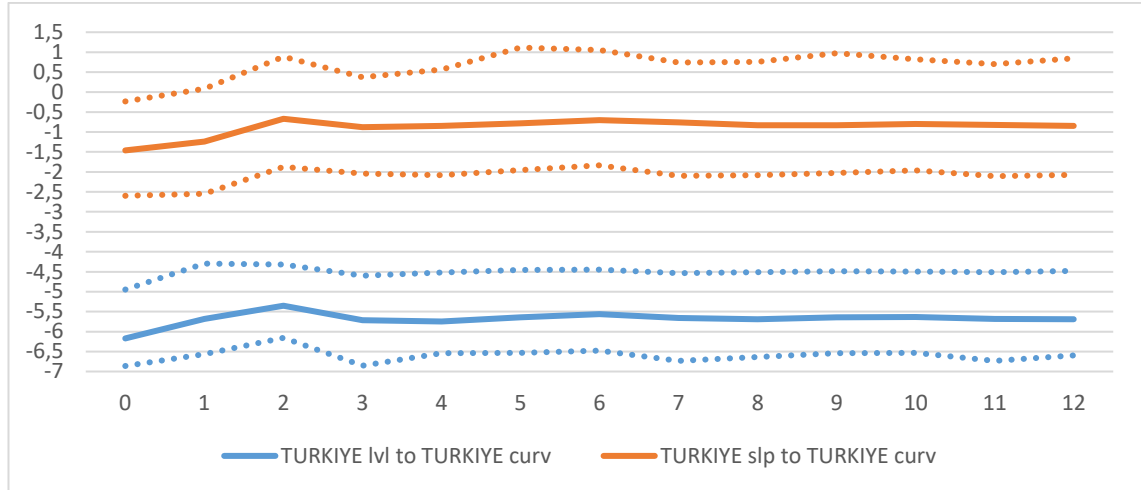


Figure 8. Response of Türkiye's Curvature to Türkiye's Level and Slope

Based on GIRF results, when the interaction between Türkiye's yield curve factors and those of other countries is examined, it is observed that Türkiye's slope factor responds to the long-term fixed/risk-free interest rates of Poland and Romania (Figure 9). Specifically, an increase in the level factor of these countries negatively affects Türkiye's slope. However, when considered together with the confidence intervals, the possibility that the upper bound of the response to Romania may take positive values suggests that this result is not statistically significant and may be random. In the case of Poland, an increase in interest rates coincides with a decline in Türkiye's slope, which may mean a flattening of the yield curve. Consequently, during the period under review, the increase in the level of the Polish yield curve and the flattening of Türkiye's yield curve is statistically significant.

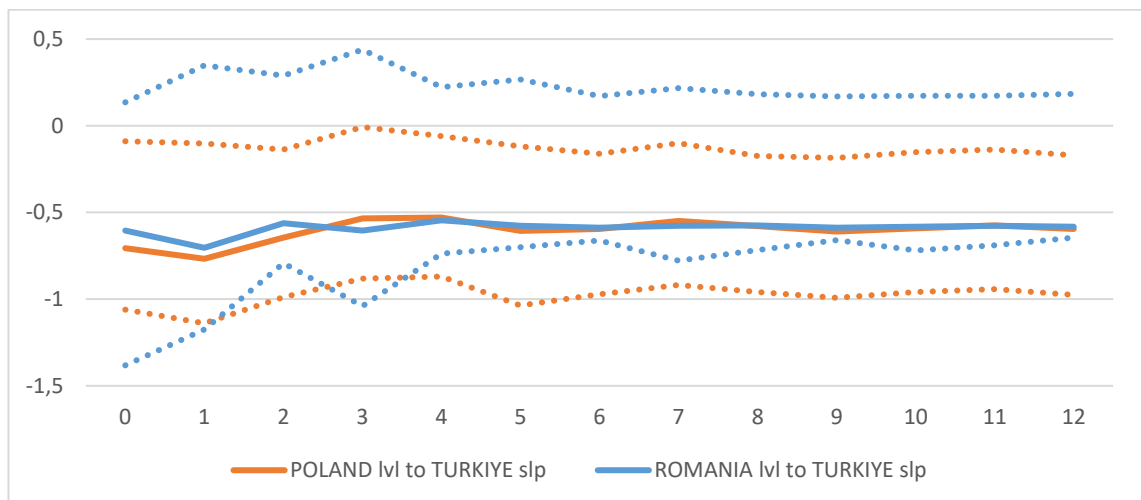


Figure 9. Response of Türkiye's Slope to Countries' Levels

When examining slope-to-slope effects and responses, Poland and Vietnam stand out in particular (Figure 10). According to the findings, an increase in the slope factor of Poland's yield curve exerts a negative impact on Türkiye's slope. The estimated response varies between -0.5 and -1 for each one-unit positive change. Based on this, it can be inferred that during the period under review, the slope factors of Poland and Türkiye's yield curves moved in opposite directions. From an economic perspective, a steepening of the Polish yield curve alongside a flattening of Türkiye's curve may indicate that while the Polish economy was gaining momentum, the Turkish economy was slowing down—or vice versa. In contrast, the slope factors of Vietnam and Türkiye exhibit a positive relationship. A one-unit increase in Vietnam's slope corresponds to an approximate 0.5-unit increase in Türkiye's slope. Economically, this suggests that although not identical, the Vietnamese and Turkish economies followed broadly similar cyclical patterns over the examined period. The confidence intervals reinforce the statistical significance of these results.

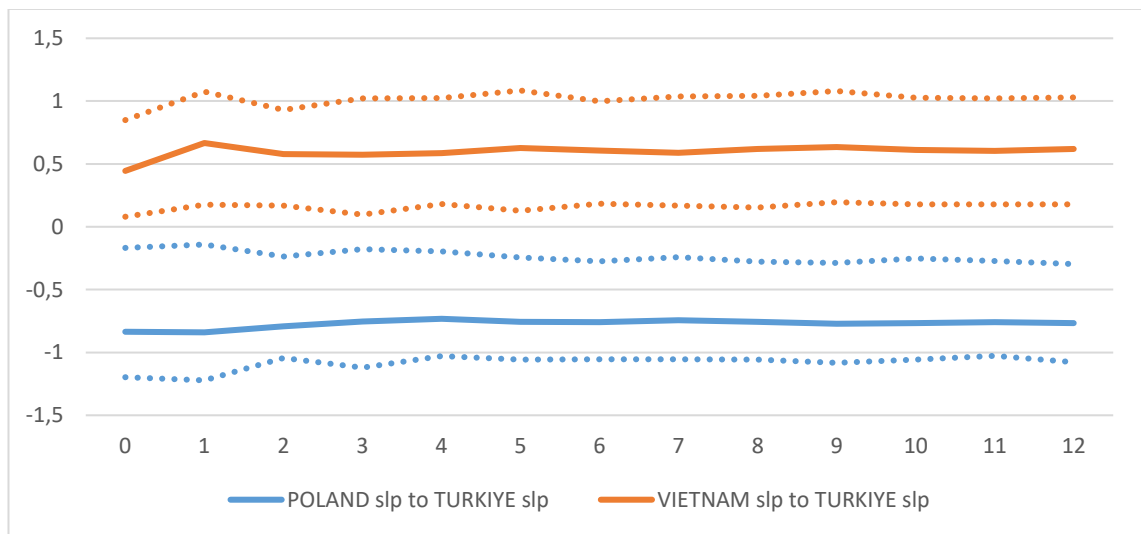


Figure 10. Response of Türkiye's Slope to Countries' Slopes

4.3. INTERACTIONS BETWEEN THE YIELD CURVE AND MACROECONOMIC INDICATORS

An analysis of the responses of Türkiye's level factor to impulses from macroeconomic indicators reveals that, with the exception of the policy interest rate, all responses are negative (Figure 11). A rising stock market reflects a vibrant economy with improving investment conditions, in which low interest rates are typically expected. In this context, a negative response of long-term interest rates to a positive stock market shock can be interpreted as an economically meaningful outcome.

During the period analysed, industrial production and inflation show an inverse but statistically insignificant relationship with the yield curve level. The policy interest rate, representing the short end of the curve, has a weak positive interaction with the level factor, bordering on statistical insignificance. In contrast, the response to the stock market is statistically significant, with confidence intervals largely in the negative range. Overall, Türkiye's yield curve level has no significant interaction with industrial production and inflation, a weak connection with the policy rate, and a significant relationship with the stock market.

In conclusion, the level of Türkiye's yield curve appears to have no statistically significant interaction with inflation and industrial production, exhibits only a weak relationship with the policy interest rate, and shows a statistically significant relationship with the stock market.

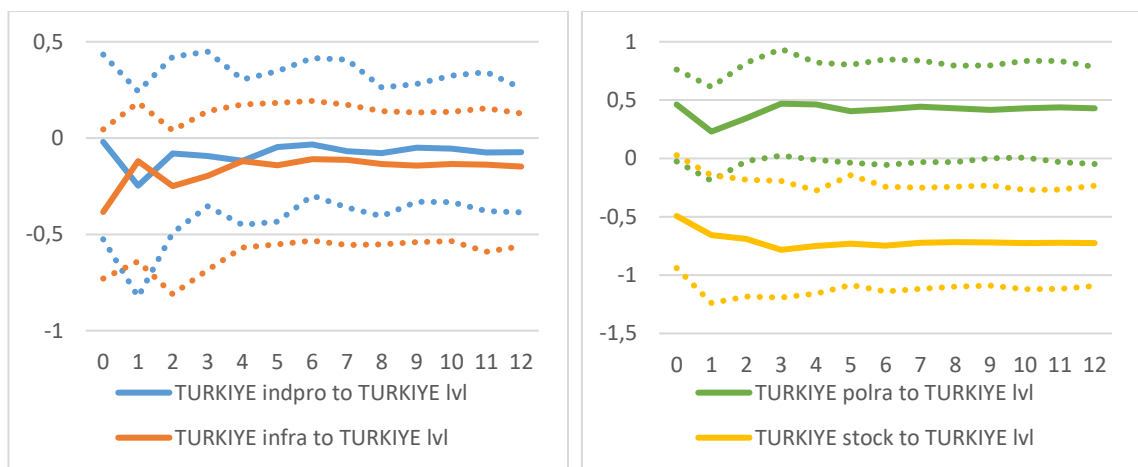


Figure 11. Response of Level to Domestic Variables

When examining foreign interactions, it is observed that during the analysed period, Türkiye's yield curve level responds only to South Korea's inflation within the medium to upper ranges (Figure 12). The direction of this response is negative. An increase in South Korea's inflation corresponds to a decrease in Türkiye's risk-free interest rate, suggesting that the two countries may be experiencing different phases of their business cycles. However, when considered alongside the confidence intervals, the finding is not statistically significant. Therefore, the response of Türkiye's yield curve level to South Korea's inflation should be interpreted as a random reaction.

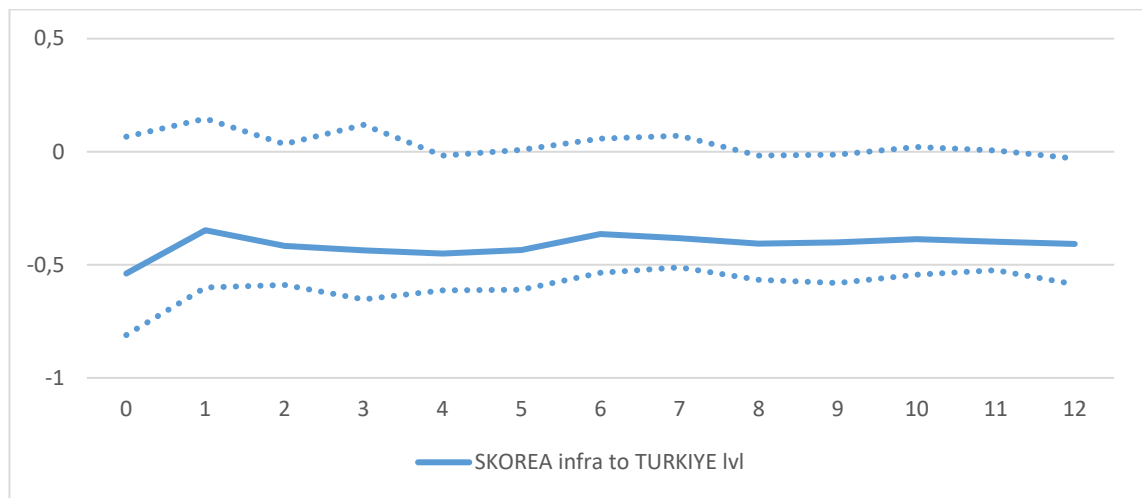


Figure 12. Response of Level to Countries' Inflation Rates

When examining the relationship between the slope of Türkiye's yield curve and domestic dynamics, it can be stated that there may be an interaction only with the inflation rate (Figure 13). Accordingly, the slope and inflation rate move in opposite directions during the analysed period. An increase of one standard deviation in the inflation rate causes a decrease of one standard deviation in the slope. The findings remain statistically significant when evaluated alongside the confidence intervals. From an economic perspective, the increase in inflation can be interpreted as reducing the slope during the analysed period. More specifically, it can be understood as the long end of the yield curve decreasing more (or increasing less) than the short end—meaning the yield curve flattens, or even inverts, as inflation rises.

A decrease in the slope (flattening or inversion) is an undesirable situation for any economy beyond a certain point. Furthermore, recalling the relationship between Türkiye's slope and level (Figures 6 and 7), the decrease in the slope could also exert a

downward effect on the level due to its positive relationship with the risk-free interest rate. At this point, it is expected that policymakers would use the policy interest rate more effectively to prevent this decline in the level. In this way, undesirable increases in inflation can be indirectly prevented.

In summary, when the policy interest rate increases, the level of the yield curve will rise, and since the level and slope are positively related, the slope will also increase. Due to the negative relationship between the level and inflation, inflation will decrease. Conversely, an increase in inflation could reduce the slope (flatten or invert it), and the decrease in the slope, due to its positive relationship, would lead to a decline in the level as well. If the rise in inflation is considered desirable, this could require a decrease in the policy interest rate. If it is undesirable, it would be expected that policymakers act in the opposite direction of the yield curve and increase interest rates.

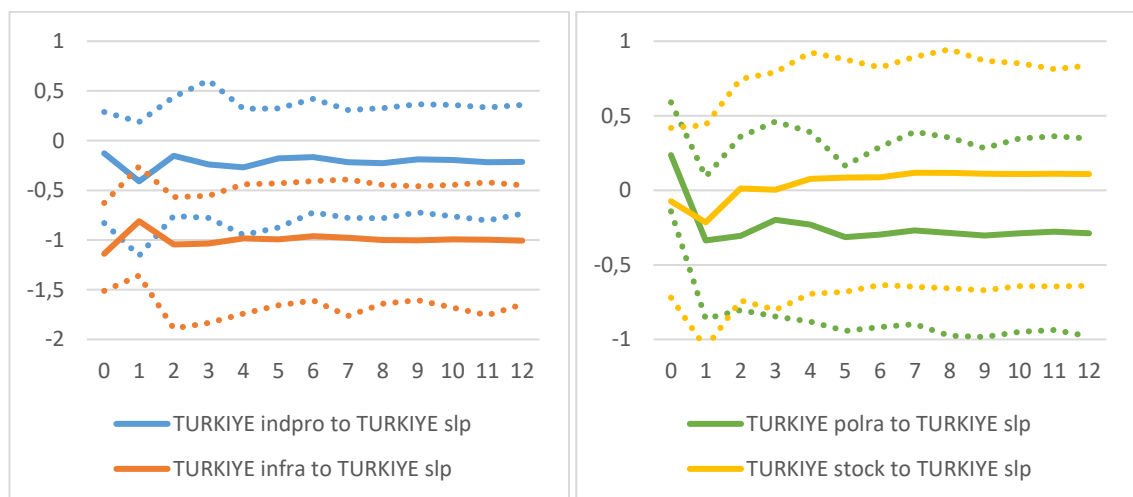


Figure 13. Response of Slope to Türkiye's Domestic Variables

When examining the interactions between the slope and foreign indicators, the inflation rates and stock markets of countries come to the forefront. An increase in the inflation rates of both Bulgaria and the United States elicits a response in Türkiye's slope (Figure 14). However, when evaluated alongside the confidence intervals, the impulse of Bulgarian inflation does not appear to be statistically significant. Although the impulse of U.S. inflation appears to be contemporaneously significant, there is no evidence of a long-term interaction. Due to the lack of statistical significance, making economic interpretations may lead to misleading or invalid conclusions.

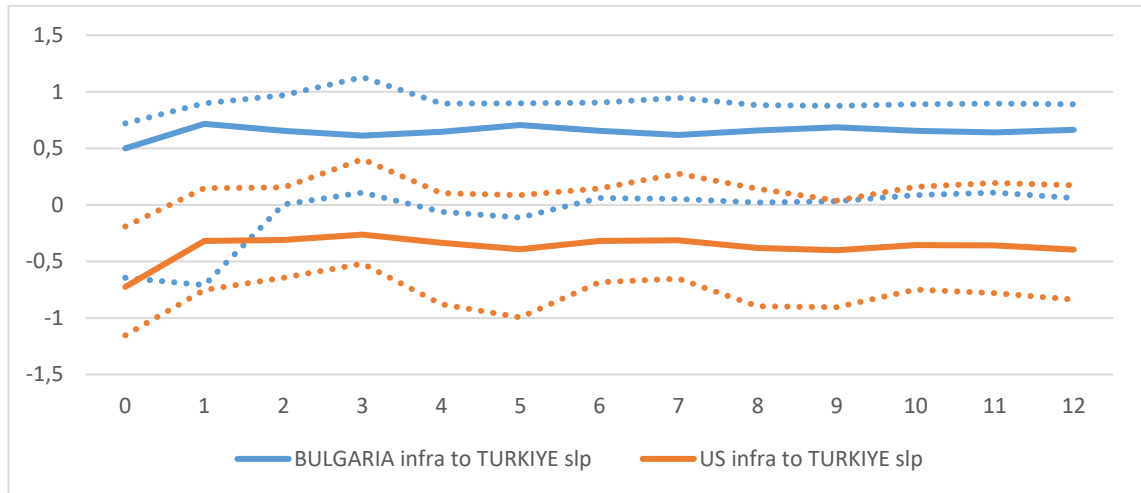


Figure 14. Response of Slope to Countries' Inflation Rates

Another foreign macroeconomic indicator that the slope responds to in GIRF is the stock markets. Accordingly, the slope of the Turkish yield curve produces negative responses to the markets of countries such as China, India, Mexico, Malaysia and South Africa (Figure 15). However, when the response of the slope to the markets is evaluated together with the confidence intervals, it is observed that the reactions of China, India, Mexico, and South Africa are not statistically significant. Although Malaysia's response appears to be statistically significant, it stands out as a very weak reaction. As a result, the response of the slope to stock markets is considered to be a random occurrence.

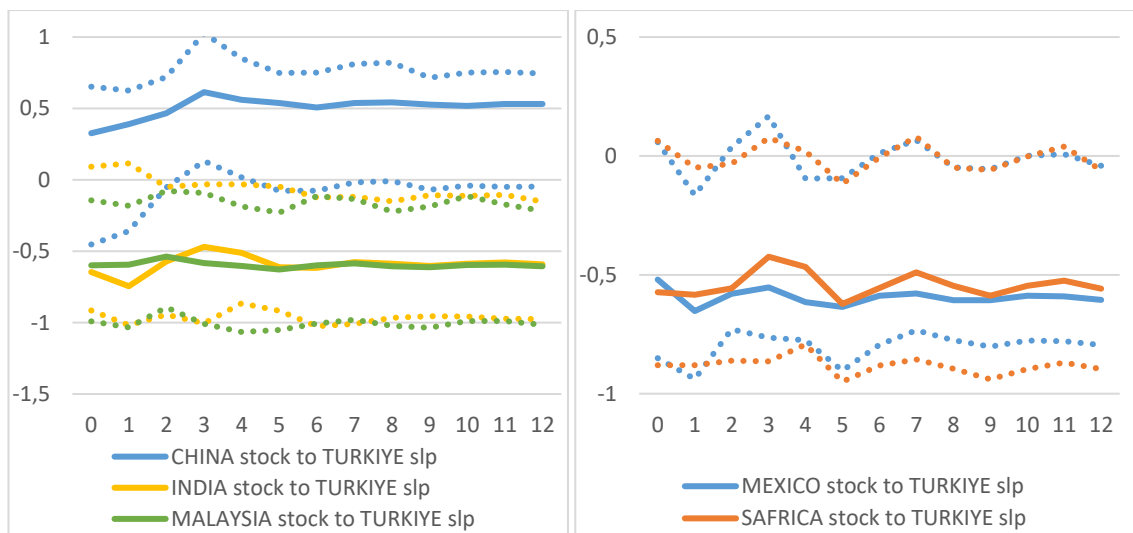


Figure 15. Response of Slope to Countries' Stock Indices

4.4. ROBUSTNESS ANALYSIS

In this section, alongside the GIRF-based findings obtained for Türkiye, the corresponding OIRFs of the key results highlighted in the GIRFs are also presented, together with their confidence intervals. The OIRF results presented in this section are intended to serve as a supplementary analysis, supporting the findings obtained from the GIRF estimations.

The ordering of variables gains significance for conducting OIRFs. Therefore, selecting an appropriate ordering criterion becomes crucial. To this end, the average GDP of countries at current prices for the period 2008–2021 was calculated using the IMF World Economic Outlook database. Based on these average values, countries were ranked from largest to smallest to reflect their relative economic sizes. However, while this ranking was applied to countries, the ordering of variables (L, S, C, Indpro, Infra, Polra, and Stock) remained unchanged.

According to the OIRFs derived based on the country ranking, the interaction from the slope to the level factor of Türkiye's yield curve diminishes significantly, moving into a minor response region (Figure 16). When compared to the GIRF findings presented in Figure 6, it is observed that the interaction among the yield curve factors has weakened.

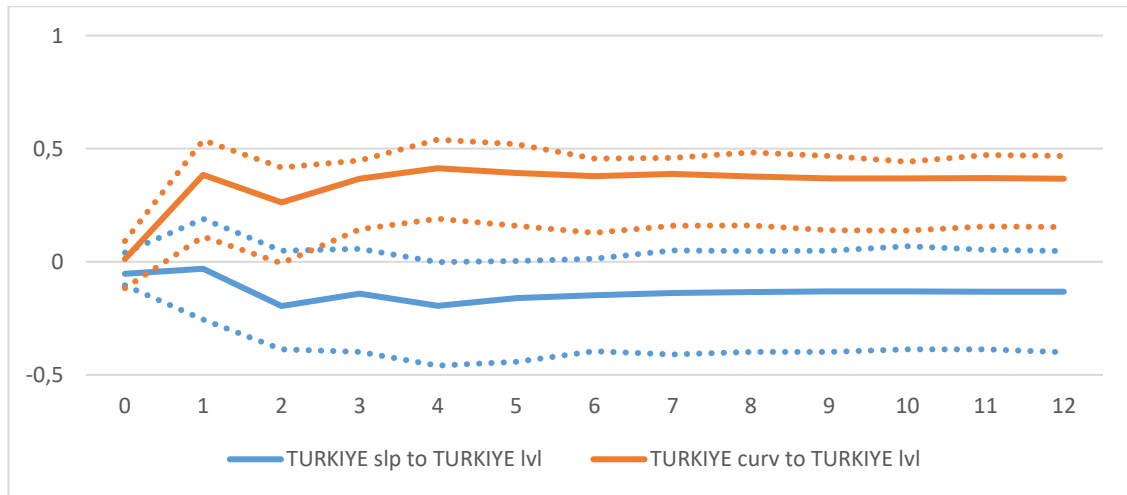


Figure 16. Response of Türkiye's Level to Türkiye's Slope and Curvature

However, a similar pattern is not observed in the OIRF results from level to slope (Figure 17). According to the findings, even when the ordering changes between indicators, a one standard deviation shock originating from the level factor continues to significantly affect

the slope. Although the intensity of the effect diminishes compared to Figure 7, there remains a significant transmission from the level to the slope. This finding is further supported by the confidence intervals, which indicate that even at the lower bound, the response of the yield curve slope in Türkiye to a shock in the level factor can reach a magnitude of one standard deviation in response to a one standard deviation shock.

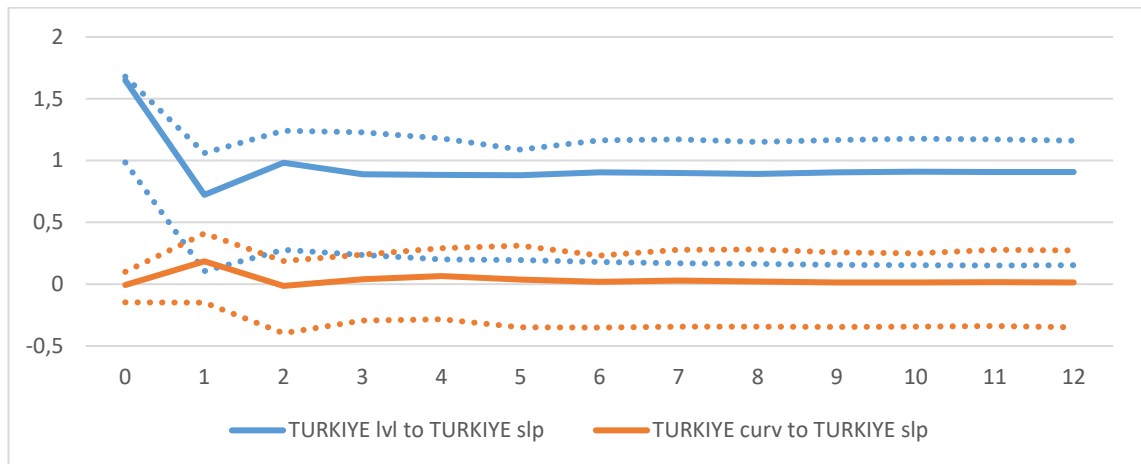


Figure 17. Response of Türkiye's Slope to Türkiye's Level and Curvature

When compared to Figure 8, the OIRF interaction from the level to the curvature does not exhibit a significant change, whereas the interaction from the slope to the curvature is observed to have increased and become mutually reinforcing (Figure 18). Although no economic interpretation is provided, this mechanically derived finding—supported by confidence intervals—emphasizes the strong interactions among the components of Türkiye's yield curve.

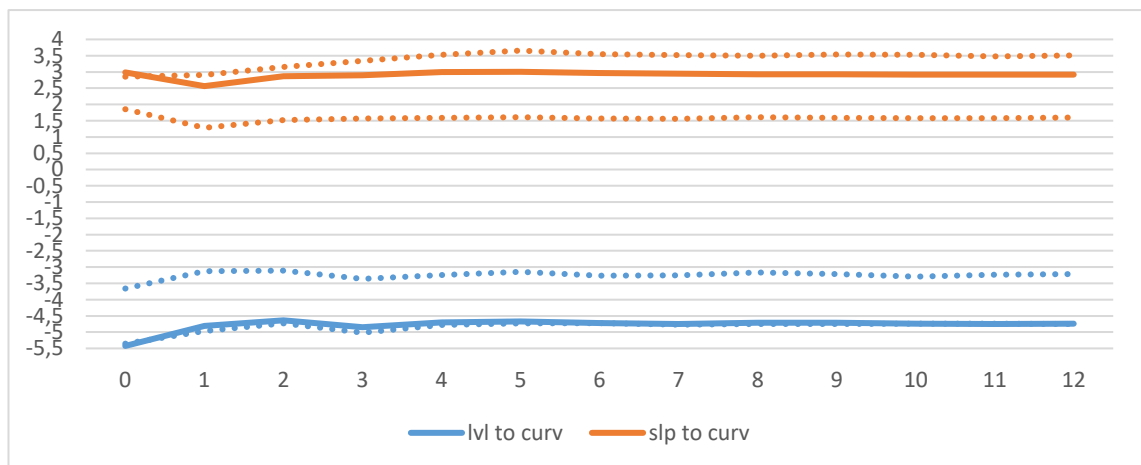


Figure 18. Response of Türkiye's Curvature to Türkiye's Level and Slope

On the side of foreign interactions, the slope of the Russian yield curve is the only factor that generates a notable response above the small region threshold at the level of the Turkish yield curve (Figure 19). This result indicates an interaction not observed in the GIRF findings. However, when evaluated together with the confidence intervals, this result does not appear to be statistically significant. Therefore, it may be considered as a reflection of a random occurrence.

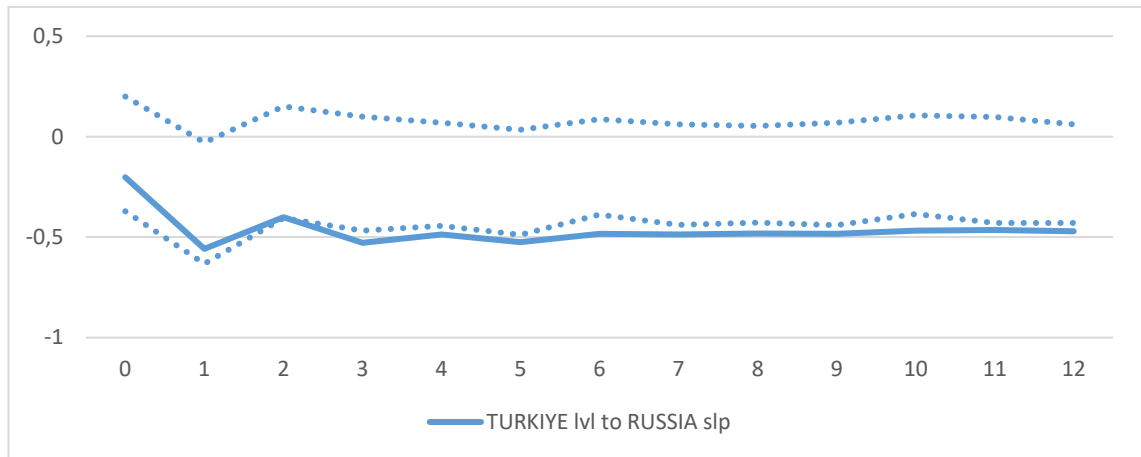


Figure 19. Response of Türkiye's Level to Russia's Slope

The OIRF interactions between Türkiye's yield curve factors and macroeconomic variables reveals that the responses of the level factor to domestic variables fall within the minor response region (Figure 20). When compared to Figure 11, which presents the GIRF findings, these responses appear to become statistically insignificant.

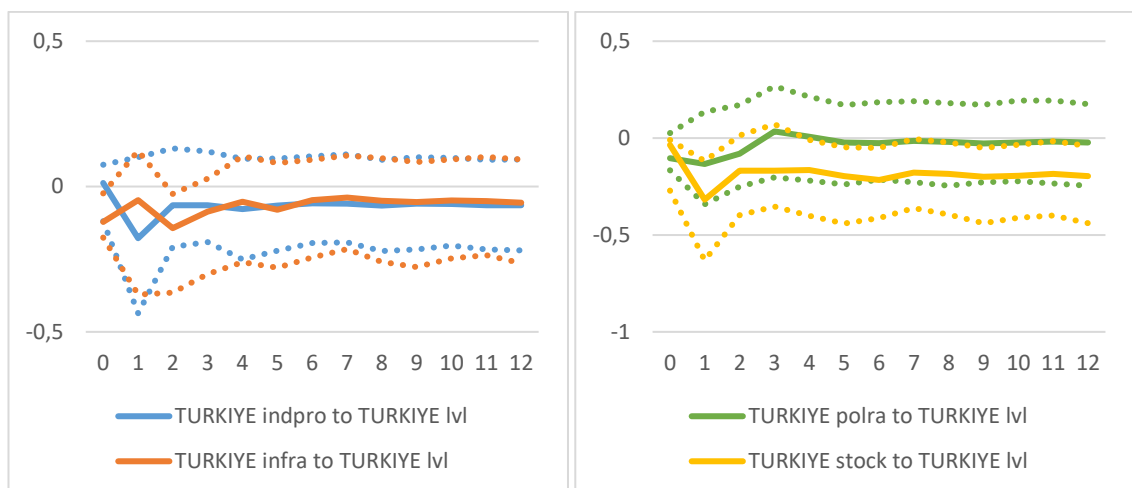


Figure 20. Response of Türkiye's Level to Domestic Variables

The interactions between domestic macroeconomic variables and Türkiye's yield curve slope show statistically insignificant responses to a one standard deviation shock (Figure 21). Similar to the GIRF results in Figure 13, the OIRF findings reveal that these responses have moved entirely into the minor response region. Even the weak response of slope to inflation is statistically insignificant in the OIRF analysis.

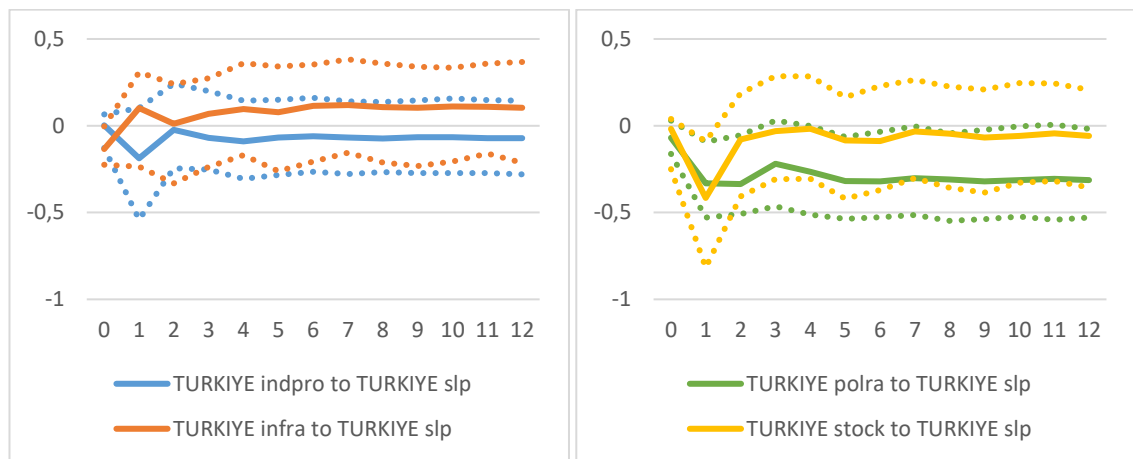


Figure 21. Response of Türkiye's Slope to Domestic Variables

On foreign macroeconomic interactions, the slope of Türkiye's yield curve exhibits a contemporaneous negative response to U.S. inflation (Figure 22). However, this response is not persistent. A closer look at the reveals that the observed contemporaneous significant relationship is also supported by the confidence intervals at the contemporaneous horizon; however, the strength of this interaction is notably weak. From the first month onward, the interaction loses its statistical significance.

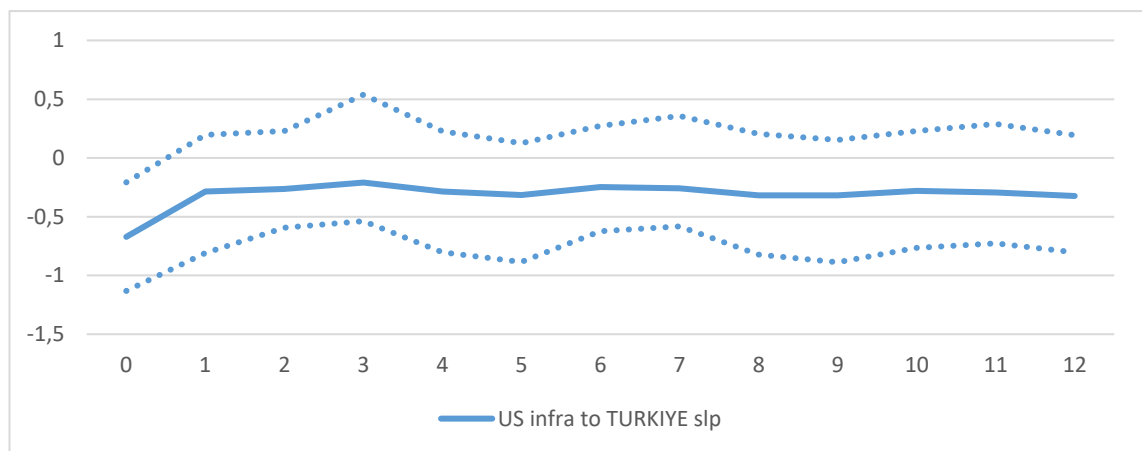


Figure 22. Response of Türkiye's Slope to U.S.'s Inflation Rate

A similar interaction is observed in the response of Türkiye's yield curve level to the shock from India's stock market (Figure 23). This response also does not exhibit persistence. Confidence intervals show that, although the contemporaneous response appears to be weakly significant, there is no statistically significant relationship in a broader sense.

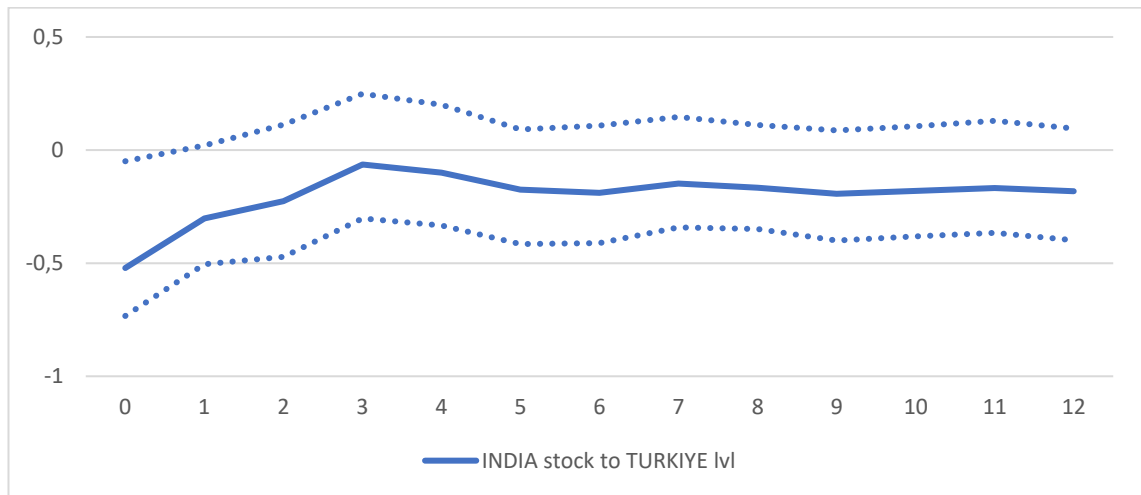


Figure 23. Response of Türkiye's Level to India's Stock Index

The responses of Türkiye's yield curve slope to Chinese and Indian stock market shocks a bit differ (Figure 24). Specifically, the Turkish slope exhibits relatively significant responses to shocks originating from the Indian stock markets. Although initially statistically insignificant, the shock to the Chinese market becomes relatively significant after the third month.

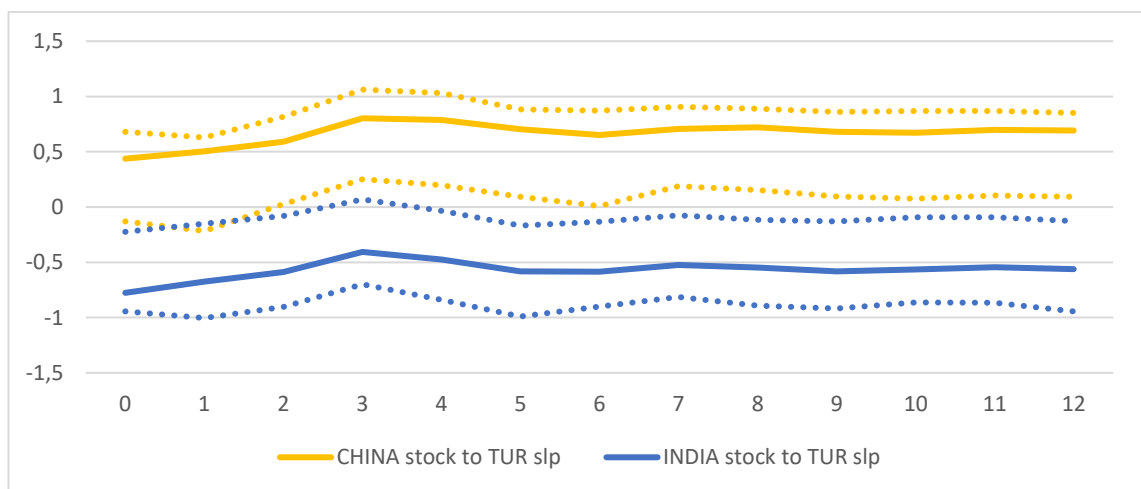


Figure 24. Response of Türkiye's Slope to China and India Stock Indices

Overall, when the OIRF findings for Türkiye are compared with the GIRF results, it is observed that the outcomes tend to become statistically less significant. At this point, the importance of variable ordering becomes evident. As the alignment of the ordering with economic theory improves, the interpretability of the results also increases. On the other hand, although the GIRF-based results offer greater flexibility due to their independence from variable ordering, theoretical consistency should still be ensured while interpreting.

The fact that both GIRF and OIRF findings indicate a significant response of the slope to a shock in the level highlights the high degree of sensitivity among the components of Türkiye's yield curve. Moreover, the relationships observed in the GIRF findings between the macroeconomic variables and yield curve components of other countries and the components of Türkiye's yield curve appear to be statistically random findings, based on the OIRF results and their associated confidence intervals.

CONCLUSION

The yield curves, which define the term structure of interest rates, can display interest rates formed both in the short-term through monetary policies and in the medium and long-term due to borrowing requirements generated by fiscal policies, all in a single representation. Given the information contained by the interest rates from different maturities, yield curves could potentially have a relationship with the fundamental economic indicators of the economy. While globalization may allow external factors to influence domestic yield curve dynamics significantly, the empirical evidence in this study suggests otherwise for Türkiye.

This study explores how Türkiye's yield curve factors are affected by each other, as well as by domestic and foreign macroeconomic variables, during the period from 2008 to 2021, using data from 19 countries. To accomplish this, a yield curve estimation method is used to calculate the yield curves of the countries, and the relationships between variables are analysed using the GVAR method. The study, which aims to understand the interactions between Türkiye's yield curve factors and both domestic and foreign indicators, emphasizes key findings derived from the results of the impulse-response functions.

The GIRF analysis reveals that Türkiye's yield curve components—level, slope, and curvature—are highly interconnected, with particularly strong and statistically significant relationships between the level and slope. These two factors move in tandem, influencing each other positively in a near one-to-one ratio. A rise in the slope leads to an increase in the overall interest rate level, and vice versa. The curvature, which captures fluctuations in the shape of the yield curve, also shows a strong but negative response to changes in the level, reacting sharply. However, the relationship between curvature and slope is weak and not statistically significant. On the foreign front, Türkiye's yield curve shows sensitivity to changes in other countries, particularly Poland and Vietnam. An increase in Poland's level is associated with a statistically significant flattening of Türkiye's yield curve, suggesting opposite economic movements. Additionally, slope-to-slope interactions reveal that Poland's steeper yield curve correlates with a flatter Turkish

curve, while Vietnam's steeper slope corresponds to a steeper Turkish slope, indicating synchronized economic trends.

The analysis shows that Türkiye's yield curve level responds negatively to most domestic macroeconomic shocks, with the exception of the policy interest rate, which has a weak positive influence. Notably, the only statistically significant relationship is between the yield curve level and the stock market, where a positive shock to the stock market leads to a decline in long-term interest rates—an economically meaningful result suggesting stronger investment conditions.

Regarding the slope of Türkiye's yield curve, a statistically significant and negative relationship is found with domestic inflation. Higher inflation flattens or inverts the yield curve, as the long-term rates decrease relative to short-term rates. This has policy implications: a flatter slope could reduce the yield curve level due to their positive link, implying the need for active use of the policy interest rate to counter inflation-driven distortions. Interactions with foreign variables, only Malaysia's stock market showed a weak yet statistically significant impact, but it was too minor to be considered economically meaningful.

Compared to GIRFs, the OIRF results for Türkiye generally show weakened and less statistically significant interactions among yield curve components and between yield curve components and macroeconomic variables. Specifically, the previously strong impact of the slope on the level of the yield curve diminishes significantly in the OIRF, while the impact from the level to the slope remains robust and statistically significant, although reduced in intensity. Additionally, the relationship from the slope to the curvature strengthens in OIRFs, showing mutual reinforcement, while the level-to-curvature link remains consistent with GIRF results. On the foreign side, OIRF results largely confirm the random or insignificant nature of foreign macroeconomic interactions suggested by GIRFs.

The findings of this thesis provide important insights in comparison to previous research on Türkiye. For example, the observed influence of inflation on the slope of the yield curve aligns with Kaya (2010), who highlights the prominent roles of inflation and exchange rates in shaping the Turkish yield curve. However, the relationship between

inflation and the level factor, as reported by Tüzün and Kahyaoğlu (2021), is not supported by the present analysis. Instead, this study identifies a significant interaction between the level factor and the policy interest rate. Furthermore, contrary to the view that external shocks are a primary driver of yield curve dynamics, the results indicate that, during the examined period, the Turkish yield curve was more responsive to domestic factors than to external influences

As a result, several important findings and policy recommendations emerge: Firstly, while the level and slope factors of Türkiye's yield curve exhibit a strong and bidirectional sensitivity to each other according to the GIRF analysis, the OIRF results indicate a unidirectional relationship, with interaction observed only from the level to the slope. Secondly, in terms of interactions with macroeconomic indicators, the GIRF findings suggest that the level responds weakly but significantly to changes in the policy interest rate, whereas the slope appears sensitive to inflation. However, these relationships are not confirmed under the OIRF framework. If the GIRF results are taken as the basis for interpretation, an increase (decrease) in the policy rate would lead to an increase (decrease) in the level due to their weak but positive relationship. Consequently, the slope would steepen (flatten) as a result of its positive interaction with the level, and a steeper (flatter) slope would, through its negative association with inflation, contribute to a decrease (increase) in inflation. Within the GIRF framework, this mechanism illustrates the monetary authority's potential to influence inflation through adjustments in the policy rate in line with its inflation targeting objectives. While this mechanism emerges from the GIRF framework and offers a plausible policy interpretation, it should be viewed as exploratory rather than conclusive, given its lack of confirmation under OIRF. Thirdly, when both the GIRF and OIRF results are evaluated alongside their respective confidence intervals, it becomes evident that the interactions between Türkiye's yield curve factors and foreign macroeconomic indicators are largely random in nature.

From a policy implementation perspective, GIRF results can serve as an effective tool for identifying the underlying transmission mechanisms and assessing their strength. However, while the OIRF analysis gains theoretical rigor through the use of a more appropriate variable ordering, practical limitations in the application of GVAR models may constrain the implementation of such ordering strategies.

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APPENDIX 1. ORIGINALITY REPORT

	HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ	Doküman Kodu Form No.	FRM-DR-21
		Yayın Tarihi Date of Pub.	04.01.2023
	FRM-DR-21 Doktora Tezi Orijinallik Raporu <i>PhD Thesis Dissertation Originality Report</i>	Revizyon No Rev. No.	02
		Revizyon Tarihi Rev. Date	25.01.2024

HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ İKTİSAT ANABİLİM DALI BAŞKANLIĞINA
Tarih: 05/08/2025
Tez Başlığı (Türkçe): Getiri Eğrisi Etkileşimleri ve Makroekonomik Göstergeler: Türkiye Örneği
Tez Başlığı (Almanca/Fransızca)*: -
Yukarıda başlığı verilen tezin a) Kapak sayfası, b) Giriş, c) Ana bölümler ve d) Sonuç kısımlarından oluşan toplam 84 sayfalık kısmına ilişkin, 16/07/2025 tarihinde şahsım/tez danışmanım tarafından Turnitin adlı intihal tespit programından aşağıda işaretlenmiş filtrelemeler uygulanarak alınmış olan orijinallik raporuna göre, tezin benzerlik oranı %22'dir.
Uygulanan filtrelemeler**: 1. ☒ Kabul/Onay ve Bildirim sayfaları hariç 2. ☒ Kaynakça hariç 3. ☐ Alıntılar hariç 4. ☒ Alıntılar dâhil 5. ☒ 5 kelimeden daha az örtüşme içeren metin kısımları hariç
Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Çalışması Orijinallik Raporu Alınması ve Kullanılması Uygulama Esasları'nı inceledim ve bu Uygulama Esasları'nda belirtilen azami benzerlik oranlarına göre tezin herhangi bir intihal içermediğini; aksinin tespit edileceği muhtemel durumlarda doğabilecek her türlü hukuki sorumluluğu kabul ettiğimi ve yukarıda vermiş olduğum bilgilerin doğru olduğunu beyan ederim.
Gereğini saygılarımla arz ederim.
ÜNAL KAYA

Öğrenci Bilgileri	Ad-Soyad	UNAL KAYA	
	Öğrenci No	N18144851	
	Enstitü Anabilim Dalı	İKTİSAT	
	Programı	İKTİSAT	
	Statüsü	Doktora ☒	Lisans Derecesi ile (Bütünleşik) Dr ☐

DANIŞMAN ONAYI

UYGUNDUR.
PROF. DR. AYŞEN SİVRİKAYA

*Tez Almanca veya Fransızca yazılıyor ise bu kısımda tez başlığı **Tez Yazım Dilinde** yazılmalıdır.

**Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Çalışması Orijinallik Raporu Alınması ve Kullanılması Uygulama Esasları ikinci bölüm madde (4)/3'te de belirtildiği üzere: Kaynakça hariç, Alıntılar hariç/dahil, 5 kelimeden daha az örtüşme içeren metin kısımları hariç (Limit match size to 5 words) filtreleme yapılmalıdır.

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	FRM-DR-21 Doktora Tezi Orijinallik Raporu <i>PhD Thesis Dissertation Originality Report</i>	Revizyon No Rev. No.	02
		Revizyon Tarihi Rev. Date	25.01.2024

TO HACETTEPE UNIVERSITY GRADUATE SCHOOL OF SOCIAL SCIENCES DEPARTMENT OF ECONOMICS
Date: 05/08/2025
Thesis Title (In English): Yield Curve Spillovers and Macroeconomic Indicators: The Case of Türkiye According to the originality report obtained by myself/my thesis advisor by using the Turnitin plagiarism detection software and by applying the filtering options checked below on 16/07/2025 for the total of 84 pages including the a) Title Page, b) Introduction, c) Main Chapters, and d) Conclusion sections of my thesis entitled above, the similarity index of my thesis is 22%. Filtering options applied**: 1. ☒ Approval and Declaration sections excluded 2. ☒ References cited excluded 3. ☐ Quotes excluded 4. ☒ Quotes included 5. ☒ Match size up to 5 words excluded I hereby declare that I have carefully read Hacettepe University Graduate School of Social Sciences Guidelines for Obtaining and Using Thesis Originality Reports that according to the maximum similarity index values specified in the Guidelines, my thesis does not include any form of plagiarism; that in any future detection of possible infringement of the regulations I accept all legal responsibility; and that all the information I have provided is correct to the best of my knowledge. I respectfully submit this for approval. ÜNAL KAYA

Student Information	Name-Surname	UNAL KAYA	
	Student Number	N18144851	
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	Status	PhD ☒	Combined MA/MSc-PhD ☐

SUPERVISOR'S APPROVAL

APPROVED
PROF. DR. AYŞEN SİVRİKAYA

**As mentioned in the second part [article (4)/3] of the Thesis Dissertation Originality Report's Codes of Practice of Hacettepe University Graduate School of Social Sciences, filtering should be done as following: excluding reference, quotation excluded/included, Match size up to 5 words excluded.

APPENDIX 2. ETHICS COMMISSION FORM

	HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ	Doküman Kodu Form No.	FRM-DR-12
		Yayın Tarihi Date of Pub.	22.11.2023
	FRM-DR-12 Doktora Tezi Etik Kurul Muafiyeti Formu <i>Ethics Board Form for PhD Thesis</i>	Revizyon No Rev. No.	02
		Revizyon Tarihi Rev. Date	25.01.2024

HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ İKTİSAT ANABİLİM DALI BAŞKANLIĞINA
Tarih: 05/08/2025
Tez Başlığı: Getiri Eğrisi Etkileşimleri ve Makroekonomik Göstergeler: Türkiye Örneği Tez Başlığı (Almanca/Fransızca)*: - Yukarıda başlığı verilen tez çalışmam: 1. İnsan ve hayvan üzerinde deney niteliği taşımamaktadır. 2. Biyolojik materyal (kan, idrar vb. biyolojik sıvılar ve numuneler) kullanılmasını gerektirmemektedir. 3. Beden bütünlüğüne veya ruh sağlığına müdahale içermemektedir. 4. Anket, ölçek (test), mülakat, odak grup çalışması, gözlem, deney, görüşme gibi teknikler kullanılarak katılımcılardan veri toplanmasını gerektiren nitel ya da nicel yaklaşımlarla yürütülen araştırma niteliğinde değildir. 5. Diğer kişi ve kurumlardan temin edilen veri kullanımını (kitap, belge vs.) gerektirmektedir. Ancak bu kullanım, diğer kişi ve kurumların izin verdiği ölçüde Kişisel Bilgilerin Korunması Kanuna riayet edilerek gerçekleştirilecektir. Hacettepe Üniversitesi Etik Kurullarının Yönergelerini inceledim ve bunlara göre çalışmamın yürütülebilmesi için herhangi bir Etik Kuruldan izin alınmasına gerek olmadığını; aksi durumda doğabilecek her türlü hukuki sorumluluğu kabul ettiğimi ve yukarıda vermiş olduğum bilgilerin doğru olduğunu beyan ederim. Gereğini saygılarımla arz ederim. ÜNAL KAYA

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	HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ	Doküman Kodu Form No.	FRM-DR-12
		Yayın Tarihi Date of Pub.	22.11.2023
	FRM-DR-12 Doktora Tezi Etik Kurul Muafiyeti Formu <i>Ethics Board Form for PhD Thesis</i>	Revizyon No Rev. No.	02
		Revizyon Tarihi Rev. Date	25.01.2024

HACETTEPE UNIVERSITY GRADUATE SCHOOL OF SOCIAL SCIENCES DEPARTMENT OF ECONOMICS	
Date: 05/08/2025	
Thesis Title (In English): Yield Curve Spillovers and Macroeconomic Indicators: The Case of Türkiye	
My thesis work with the title given above:	
- Does not perform experimentation on people or animals. - Does not necessitate the use of biological material (blood, urine, biological fluids and samples, etc.). - Does not involve any interference of the body's integrity. - Is not a research conducted with qualitative or quantitative approaches that require data collection from the participants by using techniques such as survey, scale (test), interview, focus group work, observation, experiment, interview. - Requires the use of data (books, documents, etc.) obtained from other people and institutions. However, this use will be carried out in accordance with the Personal Information Protection Law to the extent permitted by other persons and institutions.	
I hereby declare that I reviewed the Directives of Ethics Boards of Hacettepe University and in regard to these directives it is not necessary to obtain permission from any Ethics Board in order to carry out my thesis study; I accept all legal responsibilities that may arise in any infringement of the directives and that the information I have given above is correct.	
I respectfully submit this for approval.	
ÜNAL KAYA	

Student Information	Name-Surname	UNAL KAYA	
	Student Number	N18144851	
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SUPERVISOR'S APPROVAL

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PROF. DR. AYŞEN SIVRİKAYA