Master Thesis

Modelling the Yield Curve in the United States and the Euro Area

Alexander Schulz

under the supervision of

Michael Pfarrhofer, Ph.D.

September 27, 2024

To Prof. Dr. Helmut Kramer, who not only taught me how to be a considerate economist, but, more importantly, what it means to be a loving father.

Contents

List of Figures

List of Tables

1 Introduction

The global economy has become increasingly complex in recent decades, with central banks in most major economies responding to the global financial crisis by keeping interest rates near or at the the zero lower bound, which necessitated the subsequent shift of monetary policy to unconventional instruments such as forward guidance and quantitative easing (QE) in order for monetary policy to stay viable. Further complicating matters, recent idiosyncratic shocks such as the COVID-19 pandemic or the war in Ukraine have induced the start of an unprecedented global monetary tightening cycle, while geopolitical tensions in the Middle East make it even more difficult to correctly predict prospective output growth, inflation rates or the future stance of monetary policy. Altogether, these factors have dramatically influenced economic conditions around the world and lead to a high degree of unpredictability and uncertainty. This has amplified the need to refine the hitherto available tools and methods available in the economist's toolbox in order to infer as precise economic signals as possible in such volatile times.

Rooted in decades of economic research, the yield curve has oftentimes offered simplistic yet highly accurate predictions of the future path of the economy. Its various shapes, slopes and spreads are analysed, forecasted and interpreted in order to assess the state of the overall economy as well as market expectations of the future. Beware an inverted yield curve, which usually is interpreted as the market expecting an imminent recession. However, though the yield curve — mapping interest rates to specific maturities — seemingly is a key indicator for economic agents, it is oftentimes not well understood, either in a general sense and especially in regards to its dynamics with various economic variables. A contributing factor to this could be that the yield curve has been studied in a rather dichotomous fashion, either from the lens of a finance professional aiming to maximize the returns of his/her portfolio, or from the perspective of an economist concerned with predicting the future state of the economy as accurately as possible. Yet yields are known to contain a tremendous amount of information useful in both realms be it on the current stance of monetary or fiscal policy as well as expectations of future economic activity and inflation (Evans and Marshall, 2007). Likewise economic variables such as inflation expectations are oftentimes assumed to be among the main drivers of yield curve movements, though, among others, Gomez-Cram and Yaron (2020) cast doubts on this hypothesis. Nonetheless, the direction of causality and even the existence of a causal relationship per se is ambiguous, though some theories have helped uncover this fuzzy relationship.

Ever since the development of the well-known expectation hypothesis by Hicks (1946), the role agent's expectations play entered the center stage and have been key for better understanding the yield curve in an economic context. In short, the expectation hypothesis assumes that long-term interest rates are average expected future short-term rates. Now, if these short-term rates are driven by macroeconomic aggregates such as the output gap and inflation (expectations), as is assumed by the monetary policy rule developed by Taylor (1993), the yield curve allows to deduce market expectations of the future state of the economy since current long-term market yields are based on expectations of said aggregates (Gürkaynak and Wright, 2012). What is more, the expectation hypothesis is also fundamental in order to understand the implications of phenomena such as the above mentioned inversion of the yield curve. Namely, if investors anticipate a decline in future inflation or output growth due to recessionary concerns, they would expect monetary policy authorities to lower (short-term) interest rates in the future, inducing current yields at the long end of the term structure to decrease relative to the short end, potentially resulting in an inverted yield curve. The economic implications of an inversion of the term structure have been studied extensively by the likes of Estrella and Hardouvelis (1991), Estrella and Mishkin (1995), Stock and Watson (2003) and others, concluding that the yield curve — more specifically, the slope of the yield curve — seems to possess predictive power regarding the future state of the economy.

In this context, another pivotal domain for a refined understanding of the yield curve — again highlighting the importance of economic expectations — has been the role of monetary policy, especially with regards to unconventional instruments. With interest rates having been stuck at the zero lower bound in most major economies for the majority of the past decade, forward guidance and QE have become increasingly important. In this scenario, conventional tools such as lowering short-term interest rates in order to boost aggregate demand and counteract deflationary risks are no longer feasible. Therefore — under the expectation hypothesis — to provide additional stimulus to the economy and preserve the effectiveness of monetary policy, central banks need to influence market expectations accordingly via implementing said unconventional tools (Gürkaynak and Wright, 2012). However, under such distinct circumstances, it is of the utmost importance to assess the potential impacts of these monetary policy actions on the real economy. As a means to this end, high frequency event studies have become essential to identify the impacts of central bank actions for variations not only in the yield curve, but also exchange rates, inflation and stock prices. While Gürkaynak, Sack, and Swanson (2005) show that statements by the Federal Open Market Committee (FOMC) concerned with future policy actions seem to be the main driver of longer term US Treasury yields, above and beyond changes in the federal funds rate target, Swanson (2021) concludes that both forward guidance and QE have enabled the US Federal Reserve to effectively conduct monetary policy at the zero lower bound, where the former has had a significant effect on short-term Treasury yields, while the latter was the main driver of loner-term yields. Consistent with the findings for the US economy, Altavilla et al. (2019) have obtained similar results for the Euro Area, concluding that their three estimated monetary policy factors capture almost all of the variation in the yield curve. Additionally, the authors stress the necessity to take the entire term structure, and not just short-term interest rates, into account when studying the effects of monetary policy, again corroborating the significance of the yield curve for policymakers.

All of the above show that understanding the interactions between the yield curve and the macroeconomy is crucial, especially highlighting the importance of economic expectations. Both the yield curve offers valuable insights into agent's expectations of the future state of the economy, while inflation expectations and monetary policy actions seem to induce yield curve movements. Thus, correctly assessing the impacts of future developments in both macroeconomic factors such monetary policy, as well as the term structure seems invaluable for portfolio managers and economists alike. Ultimately, a precise understanding of the underlying drivers, be they of economic or financial nature, enables central banks to calibrate their policies to current market conditions and expectations, as well as giving asset managers the opportunity to position their portfolios profitably. But how exactly is the yield curve related to the economy? Is the yield curve really a leading indicator for economic activity? Are economic expectations really determining the shapes and movements of the yield curve? Could there even be a bidirectional link, where the causality runs in both directions? This thesis is aimed at answering these questions.

Stemming from the methodology introduced by Diebold, Rudebusch, and Aruoba (2006), a decomposition of the United States and Euro Area yield curves using the well-known model introduced by Nelson and Siegel (1987) is conducted, yielding the three latent factors representing the level, slope and curvature. In a second step, a structural vector autoregression (SVAR) model is estimated including said factors along with various economic variables. Based thereupon, distinct structural shocks are obtained using short-term restrictions via a Cholesky decomposition of the reduced form variance-covariance matrix of the error term. The resulting impulse responses are utilized for the sake of deducing potential interpretations regarding the dynamic interactions between the macroeconomy and the yield curve.

The thesis is structured in the following way. Section 2 offers a brief overview of the literature, highlighting past findings regarding the yield curve's relevance and connection to macroeconomic factors. Section 3 introduces the methodological approach implemented. The subsequent Section starts with an overview regarding the data used (Section 4.1) as well as presenting the empirical results for the United States (Section 4.2) and the Euro Area yield curves (Section 4.3), where the relevance of macroeconomic variables as drivers of yield curve movements is assessed, while simultaneously examining the impacts changes in the yield curve factors have on economic variables. Section 4.4 offers a comparative examination of the results obtained for the United States and the Euro Area, where the main similarities and differences are highlighted. Thereafter, a conclusion summarizing the main findings is provided.

2 Literature Review

Historically, there has been an abundance of literature about both the term structure of interest rates per se, as well as its connection to economic activity. This section aims at narrowing down this wealth of research, providing an overview of the hitherto available and relevant literature, focusing on identifying the potential one- or bi-directional link between the yield curve and the economy. Thus, it follows the distinction provided by Diebold, Rudebusch, and Aruoba (2006), who divide this research into yields-to-macro versus and macro-to-yields studies.

Some of the central contributions regarding the yields-to-macro relationship have come from Harvey (1988), who shows that the expected real term structure contains information about future consumption growth. Among other researchers, Estrella and Hardouvelis (1991), Estrella and Mishkin (1995) and Estrella and Mishkin (1996), use a probit model approach, estimating the probability of historical recessions as a function of the term spread,[1] through which the authors have provided some remarkable results corroborating the hypothesis in regard to the relevance of the yield curve (slope) for future macroeconomic activity, at least for the US and other major European economies such as Germany, the UK and France. In a similar fashion, Bernard and Gerlach (1998) extend the analysis to other major economies such as Canada, Japan, Belgium and the Netherlands, confirming the finding that the term spread offers significant information regarding future recessions. Solely for Japan the significance is limited, which can possibly be attributed to differences in financial regulation and the fact that interest rates in Japan did not fully reflect market participants expectations of the future path of the economy (Bernard and Gerlach, 1998). Evgenidis, Papadamou, and Siriopoulos (2018) offer a meta-analysis of the yields-to-macro view, again focusing on the yield spread's ability to forecast economic activity. Although they again corroborate the findings of the previous 30 years, they note that the modelling strategy should take non-linearities into account as well as underlining the importance of incorporating monetary policy variables into the models, as some predictive power of the yield spread is attributed to expectations about the future path of monetary policy. The authors also note that there still is no widely accepted theory explaining the usefulness of the yield curve. Apart from these rather promising studies affirming one's confidence in the yields-to-macro view, authors such as Dotsey (1998) and Stock and Watson (2001) note that yields

[1] The term spread is generally known as the difference between a long-term and a short-term interest rate, e.g. the difference between the 10-year and 3-month government bond yields

(spreads) have somewhat lost their predictive ability ever since the 1980s.

On the spectrum of authors leaning towards a macro-to-yields approach, central research has come from Evans and Marshall (1998), Ang and Piazzesi (2003) and Evans and Marshall (2007), all using some variation of a VAR framework. Using three different identification strategies within a VAR setting, Evans and Marshall (1998) find that monetary policy shocks primarily have a significant effect on short-term interest rates while also reducing expected inflation, implying a rise in the real interest rate. The authors interpret this as monetary policy having a significant effect on the yield curve through a liquidity, rather than an expected inflation effect. Though delivering promising results of a potential macro-to-yields relationship, one key weakness is the sole focus on monetary policy shocks alone, whilst excluding other macro variables. Counteracting these shortcomings and extending their previous research, Evans and Marshall (2007) include other macro variables into their model, such as technology, fiscal policy and preferences for current consumption, an identification set predominantly derived from previous research on DSGE models. As before, they conclude that, apart from fiscal policy shocks, macroeconomic factors such as technology are able to explain a large part of yields movements along the short- to medium- end of the curve. By including multiple macro variables into a multi-factor model of the term structure, using the assumption of no-arbitrage as an identifying restriction, Ang and Piazzesi (2003) find that macro variables explain a tremendous amount of the variation in bond yields, especially at the short-end of the curve, where the main drivers are shocks to inflation, which is consistent with previous findings by Evans and Marshall (1998). The authors also conclude that incorporating macro factors in latent factor term structure models enhances out-of-sample forecasts. In contrast, now taking the stance of the opposite direction of causality, i.e. yields-to-macro, Ang, Piazzesi, and Wei (2006) offer a comparison to previous research such as Estrella and Hardouvelis (1991). Through estimating a relatively simple VAR only including a set of yields and GDP growth, they conclude that the nominal short rate dominates the slope of the yield curve in predicting future economic activity.

Some other notable contributions in the realm of linking the macroeconomy and the yield curve have come from Dewachter and Lyrio (2006) and Rudebusch and Wu (2008). Both sets of authors extend the latent factor model of the term structure with macroeconomic factors. The former specifically reference to Ang and Piazzesi (2003) in the context of a possible model misspecification, since previous research has apparently failed to correctly model the long end of the yield curve. Through their slightly modified approach, the authors introduce long-run inflation expectations in their model and show that not only the short-end of the yield curve, but also longer maturities are indeed driven by macroeconomic variables. They also suggest interesting and seemingly plausible interpretations to the latent factors, chiefly among them finding that the level factor is closely related to the aforementioned long-run inflation expectations. Rudebusch and Wu (2008) combine a small scale macro model, assuming that the short-term rate is represented by a monetary policy reaction function, such as the well known function developed by Taylor (1993), with a standard no-arbitrage latent factor model of the term structure, where the short-term interest rate is modelled as a function of latent factors often interpreted as a level and/or slope factor. Through this approach, the authors are able to synthesize both the finance and the economists approach to modelling interest rates. Obtaining promising results, they offer insightful and intuitive interpretations, e.g. how the level factor and the central banks inflation target are linked, underlining the significance of a holistic approach.

Among the major contributions regarding the application of the Nelson and Siegel (1987) method in a macroeconometric framework are Diebold and Li (2006). Since other prominent theoretical models of the yield curve, chiefly among them are the no-arbitrage as well as equilibrium models, fail to provide the tools necessary for accurate predictions, the authors try to fill this gap using the aforementioned and well-known Nelson-Siegel decomposition. More precisely, the authors compare the term structure forecasting performance of said strategy with that of various benchmark forecasts (e.g. random walk) in order to test their hypothesis that a Nelson-Siegel approach yields superior out-of-sample forecasting results. Through decomposing a set of yields, representing the term structure, into three factors, which are then assumed to be evolving as an AR(1) process over time, Diebold and Li (2006) obtain forecasts of the yield curve based on the forecasts of said factors. The authors find that this approach appears to yield superior forecasts, especially at longer horizons of one year and beyond. Their promising results are one of the main reasons, why a Nelson-Siegel factor model approach has been chosen for this thesis. Another central contribution of the authors is their theoretical as well as empirical argumentation regarding the interpretation of the Nelson-Siegel factors as representing the level, slope and curvature of the decpomposed yield curve. This interpretation is conveniently used in Section 4 to get a first glimpse how well the estimated factors approximate their theoretical counterparts.

One of the central papers serving as an inspiration and template alike for this thesis is the seminal work by Diebold, Rudebusch, and Aruoba (2006). Extending upon the bipartite available literature at that time, the authors are among the most significant to investigate the joint dynamics of both macro and financial variables (i.e., level, slope and curvature factors representing the yield curve). They build upon the approach used by Diebold and Li (2006), using a state-space representation of the Nelson-Siegel model, estimated via maximum-likelihood using the Kalman filter, which simultaneously models the dynamics of the yield curve for each point in time as well as the dynamics of other variables. Through this one-step approach the authors investigate the relationship between the macroeconomy and yields, laying forth the research question of this thesis, how bond yields and the macroeconomy are linked and, more interestingly, if there is a one- or bi-directional relationship. Diebold, Rudebusch, and Aruoba (2006) conclude that there is strong evidence for a macro-to yield effect and a somewhat weaker evidence for the yield curve to affect (future) macroeconomic dynamics.

Using the same two-step approach as in this thesis, some interesting contributions for emerging economies such as India and Chile, have come from Kanjilal (2011) and Morales (2010), respectively. Both authors find evidence of a potential bi-directional link between macroeconomic variables and the yield curve. Interestingly, Kanjilal (2011) finds a stronger evidence for the yields-to-macro direction, which supports the literature by authors such as Estrella and Hardouvelis (1991) and somewhat contrasts the findings by Diebold, Rudebusch, and Aruoba (2006). Suitably for this thesis, Morales (2010) compares the two-step estimation approach introduced by Diebold and Li (2006) with the more complicated state space representation (one-step estimation process) by Diebold, Rudebusch, and Aruoba (2006) and concludes that the simplified estimation methodology does not contradict the basic intuition of the results. Furthermore, the author finds evidence for a two-way relationship between yield curve factors and macroeconomic variables for the Chilean economy.

It is again important to note the relevance of monetary policy to enhance one's understanding of the yield curve, especially highlighting the relevance of the yield curve for conducting monetary policy at the zero lower bound. Some recent papers have made valuable contributions to this end. Krippner (2012) proposes a modified approach to estimate a (Gaussian) term structure model when interest rates are near the ZLB, while Krippner (2013) offer a pioneering framework in order to identify the stance of monetary policy when the term structure is in a ZLB environments via estimation of a so-called "shadow short rate". Wright (2012) finds that unconventional monetary policy has had a stimulative effect on the US economy, lowering government and corporate bond yields, though the effect has been quite modest. Hamilton and Wu (2012) compare the effects of monetary policy, in particular the maturity structure of publicly held government bonds, on US interest rates without and within a ZLB environment, concluding that QE enables central banks to lower long-term interest rates with a similar magnitude compared to restructuring the maturity profile of the central bank government bond portfolio, e.g. by selling short-term bonds in order to buy long-term bonds. Using the shadow rate concept introduced by Krippner (2013), Bauer and Rudebusch (2016) use dynamic term structure models based on shadow rates to forecast short-term rates, i.e., the future stance of monetary policy, and find that said models improve forecasting accuracy. Wu and Xia (2016) have been influential in estimating a shadow federal funds rate for the US using a shadow rate term structure model (SRTSM) in order to measure the stance of monetary policy at the ZLB, while also making their estimated shadow rate publicly available. The authors show that the shadow federal funds rate has been crucial to understand the dynamics between monetary policy shocks and the real economy stuck at the ZLB. Specifically, expansionary monetary policy actions using unconventional instruments such as forward guidance and QE have boosted economic growth and decreased the unemployment rate, effectively demonstrating that the Fed has been able to conduct monetary policy even while being constrained by the zero lower bound. Prominent contributions have also come form Gürkaynak, Sack, and Swanson (2005), E. Nakamura and Steinsson (2018), Altavilla et al. (2019), Jarociński and Karadi (2020), Swanson (2021), Bauer and Swanson (2023) and Nakamura, Sudo, and Sugisaki (2024), each providing critical insights into how central bank announcements in major economies such as the US, the EA and Japan have enabled monetary policy authorities to conduct monetary policy while being limited by the available policy instruments, where the yield curve — particularly the long end — has been crucial to influence agent's expectations and provide economic stimulus.

Notable theoretical contributions have come from Hicks (1946), who is among the economists credited with developing the well-known expectations theory. Though it has been tested, challenged and modified by influential works such as Campbell and Shiller (1991), underlining the importance of time varying risk premia for understanding long-term rates, it is still relevant to this day in order to get an intuitive understanding of the importance of expectations regarding the interactions between the yield curve and the macroeconomy. What is more, said risk premia seem to be influenced by macroeconomic variables such as inflation (uncertainty) or monetary policy in the form of large scale asset purchases, again underlining the existence of a presumable link between the term structure and the economy worthy of a closer examination (Gürkaynak and Wright, 2012). The expectation hypothesis is also tested by Diebold, Rudebusch, and Aruoba (2006), who find evidence that it holds fairly well over some periods, but not their entire sample. Worth mentioning is the work by Kessel (1971), who offers a broad overview of common (past) theories explaining the term structure of interest rates.

Recent advancements in modeling government bond yields have focused on Bayesian modelling approaches and how-well these modelling strategies can be implemented in a machine learning framework. Papers by Carriero (2011) and Carriero, Kapetanios, and Marcellino (2012) present an innovative approach to forecasting government bond yields using a Bayesian Vector Autoregression (BVAR) framework. The authors show that their BVAR approach outperforms both standard VARs and well-known yield curve models such as the Nelson-Siegel model used in this thesis in out-of-sample forecasting. Fischer et al. (2023) propose a General Bayesian time-varying parameter vector autoregression (TVP-VAR) model for analyzing government bond yields, demonstrating that their model enhances the ability to capture complex dynamics in yield curves. Similar to this work, Carriero, Clark, and Marcellino (2021) introduce no-arbitrage priors and drifting volatilities to improve the modeling of the term structures, while Pedersen and Swanson (2019), among others, offer a comprehensive examination of the countless approaches available in a machine learning framework. These papers represent a small subset of studies contributing to a growing body of literature that aims to better forecast and understand the behavior of government bond yields within today's dynamic economic environment based on innovative and advanced modelling strategies.

3 Methodology and Data

3.1 The Nelson-Siegel model

This section is aimed at outlining the methodology applied in this thesis. After giving a comprehensive primer on the aforementioned model of the yield curve established by Nelson and Siegel (1987), the identification strategy for the VAR model containing macroeconomic and yield curve variables is introduced.

The first step of the two-step methodological approach involves modelling the yield curve using the Nelson-Siegel three factor model. The genius of the Nelson-Siegel decomposition lies within its flexibility as well as its parsimony. Based on a set of observable yields, the model is able to capture a wide range of yield curve shapes in a rather simplistic manner by decomposing the entire term structure solely into three factors. Another core strength is its ability to enable analysts to inter- and extrapolate between yields within the sample, thus providing yields for all maturities along the curve. As mentioned in section 2, the Nelson-Siegel model performs relatively well in out-of sample forecasting. What is more, though it does not explicitly ensure the absence of arbitrage, Coroneo, Nyholm, and Vidova-Koleva (2011) show that the Nelson-Siegel model aligns with the assumption of no-arbitrage. Given these highly promising attributes, the Nelson-Siegel approach appears to be well suited for the task at hand.

Following the representation of Diebold, Rudebusch, and Aruoba (2006), while also leaning on the foundational work provided by Diebold and Li (2006), the yield curve at any time t is thus assumed to be represented as the Nelson and Siegel (1987) model:

$$y_t(\tau) = L_t + S_t \left(\frac{1 - \mathrm{e}^{-\lambda\tau}}{\lambda\tau} \right) + C_t \left(\frac{1 - \mathrm{e}^{-\lambda\tau}}{\lambda\tau} - \mathrm{e}^{-\lambda\tau} \right) + \varepsilon_t, \tag{1}$$

where $t = 1, \dots, T$, $y_t(\tau)$ is a set of N yields, each with a distinct maturity τ, used for the decomposition, L_t, S_t, C_t and λ are the parameters to be estimated, while ε_t represents the error term. The regressors, which are also known as the factor loadings, are central for ensuring the flexibility to represent various yield curve shapes, where λ shows their respective rate of decay. The loading on L_t is 1 for all maturities, while the loading on the second factor, S_t starts at 1 and decays monotonically towards 0. Finally, the loading on the third factor, C_t, starts at 0, increases, but then decays back to 0. The significance of the λ coefficient can be seen in Figure 1, illustrating the factor loadings given a set of two different values for the rate of decay. While the level factor is 1 regardless of λ, it is evident that a higher λ implies a faster decay towards 0 of the slope and curvature factor loading. As a result, the lower the estimated λ coefficient, the higher the loading induced by yields at longer maturities for both the slope and the curvature factor. Moreover, λ determines where the loading on C_t reaches its maximum, where a lower rate of decay implies a maximum at a relatively longer maturity. In this context, Figure 2 offers a concrete example showing the US Treasury yield curve as of December 2019 based on data provided by Liu and Wu (2021) along with the estimated factor loadings. One can see that the yield curve is upward sloping, though there is a clear hump at the short as well as the long-end end. The long-term factor is one regardless of the maturity. The slope factor is (per definition) at its maximum at the 1-month maturity, decreasing exponentially with increasing maturity, and hence having the highest loadings at the short-end. The medium-term factor is increasing, reaching — rather prematurely — its maximum around the 14-month maturity, after which it is decreasing towards 0.

As shown by Diebold and Li (2006), the regression coefficients can have economically meaningful interpretations, i.e. they are the time-varying level (L_t), slope (S_t)[2] and curvature (C_t) factors, respectively. What is more, L_t can be thought of as the long-term factor since the loading is identical for all maturities, implying that an increase in the level factor increases all yields across the entire yield curve. By contrast, the slope factor is interpreted as the short-term factor since short-term rates induce a heavier loading on S_t, thereby changing the slope of the yield curve. Similarly, the curvature factor is considered as the medium-term component since medium-term yields tend to have the highest loading, while simultaneously an increase in C_t will mainly increase medium-term yields. The contribution of each factor loading to the overall shape of the estimated yield curve is thus given by each respective factor, e.g. L_t shows the contribution of the long-term factor, S_t that of the short-term component, while C_t illustrates the contribution of the medium-term component (Nelson and Siegel, 1987).

[2]As shown by Diebold and Li (2006), S_t equals the negative slope, that is, the difference between short-term and long-term yields

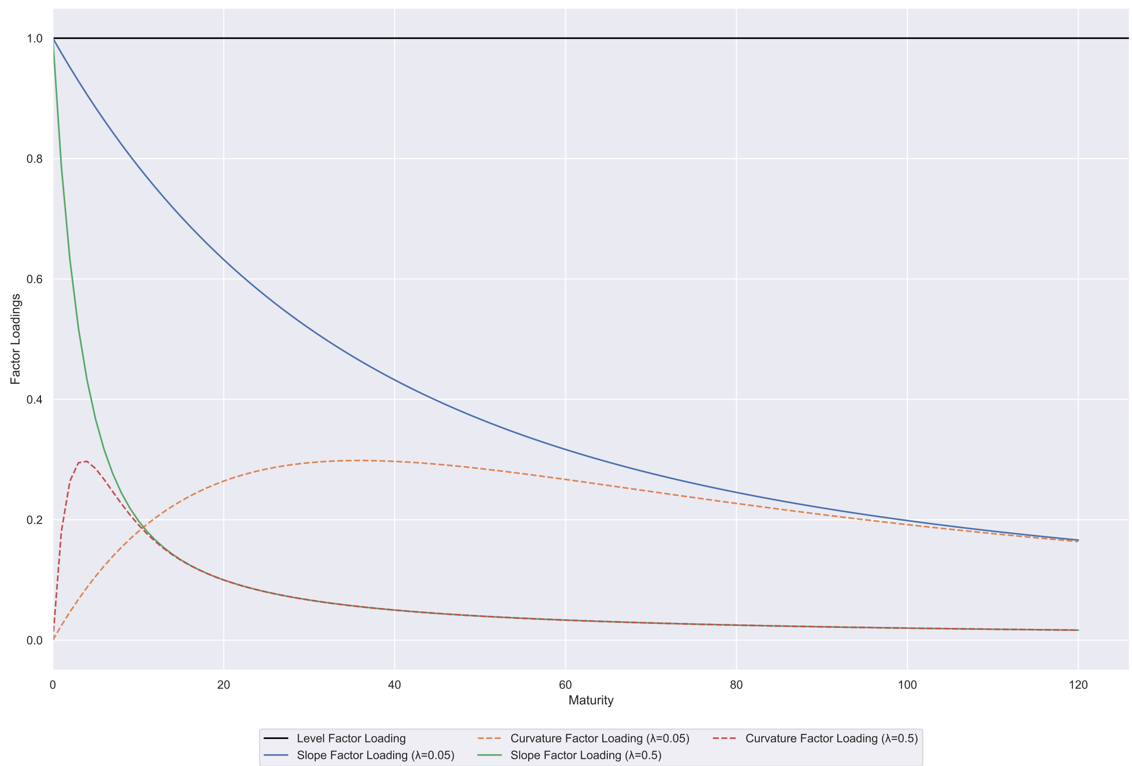

Figure 1: Exemplary Nelson Siegel Factor Loadings

As described in Nelson and Siegel (1987), the estimation[3] can be conducted in the following way. For a provisional value λ, the sample values for the factor loadings are calculated. Based thereupon, the best-fitting yield curve factors are estimated using ordinary least squares (OLS). This procedure is repeated over a grid of values for λ, yielding the overall best-fitting values for λ, L_t, S_t, and C_t. Alternatively, λ can be chosen beforehand after which the best fitting Nelson-Siegel factors are estimated based on the imposed loadings at a specific maturity. As done by Fischer et al. (2023) — based on the work by Diebold and Li (2006) — the estimation of the three yield curve factors in this thesis is implemented by setting the rate of decay to $\lambda = 0.7308$ and fitting the Nelson-Siegel model to the prevailing yield curve for each time period t in the sample, resulting in the best fitting a level (L_t), slope (S_t) and curvature (C_t) factors, respectively. Consequently, these factors are assumed to be an approximate representation of the yield curve at any given time t —dramatically reducing the dimensionality compared to including each yield separately — and, together with the macroeconomic variables, are included in a VAR(p) model aimed at studying the link between the economy and the yield curve.

[3]The estimation of the yield curve factors in this thesis is conducted using the Nelson.Siegel method from the R package YieldCurve

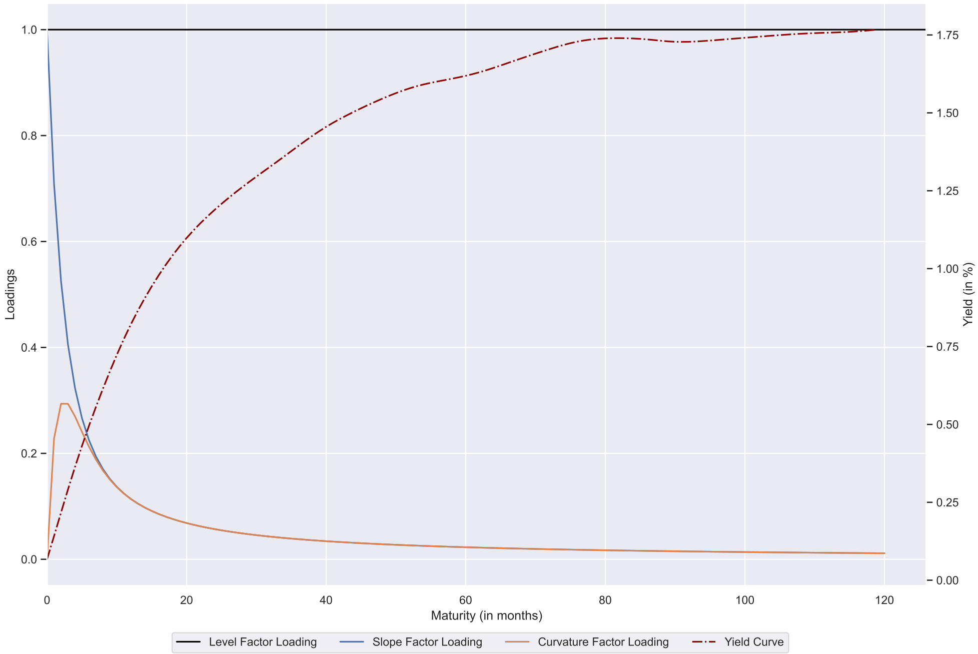

Figure 2: Actual Nelson Siegel Factor Loadings

Note: This figure provides a graphical illustration of the Nelson Siegel factor loadings based on the US Treasury yield curve as of January 2022 ($\lambda = 0.7308$).

3.2 Vector autoregression

Aforesaid VAR(p) model forms the second step of the analysis and — ignoring the vector containing the intercept terms c — is represented in the following way:

$$\mathbf{Y}_t = \sum_{p=1}^{p} \boldsymbol{A}_p \mathbf{Y}_{t-p} + \boldsymbol{\varepsilon}_t, \ \ \boldsymbol{\varepsilon}_t \sim \mathcal{N}\left(0, \boldsymbol{\Sigma}_{\boldsymbol{\varepsilon}}\right), \tag{2}$$

where Y_t denotes the $(K \times 1)$ matrix containing K endogenous variables, c is a $(K \times 1)$ vector of intercept terms, p denotes the maximum lag length, A_p is a $(K \times K)$ matrix of the autoregressive coefficients for lag length p and ε_t is a $(K \times 1)$ matrix of the reduced-form error terms.

The identification strategy is based on a structural VAR approach using contemporary recursive restrictions via a Cholesky decomposition of the variance-covariance matrix of the reduced-form errors Σ_ε. Largely following the notation of Kilian and Lütkepohl (2017), the representation of the structural VAR — again ignoring the intercept vector c — as well as the relationship between the reduced-form and structural form VAR can be seen by:

$$
\begin{aligned}
&\boldsymbol{B}_0\boldsymbol{Y}_t = \boldsymbol{B}_p\boldsymbol{Y}_{t-p} + \boldsymbol{\omega}_t,\ \boldsymbol{\omega}_t \sim \mathcal{N}(0,\boldsymbol{I}),\\
&\underbrace{\boldsymbol{B}_0^{-1}\boldsymbol{B}_0}_{\boldsymbol{I}}\boldsymbol{Y}_t = \underbrace{\boldsymbol{B}_0^{-1}\boldsymbol{B}_p}_{\boldsymbol{A}_p}\boldsymbol{Y}_{t-p} + \underbrace{\boldsymbol{B}_0^{-1}\boldsymbol{\omega}_t}_{\boldsymbol{\varepsilon}_t},
\end{aligned}
\tag{3}
$$

where ω_t is the serially uncorrelated vector of the structural shocks. Since these structural shocks permit to deduce causal conclusions based on the correlations within the data, the central aim of this thesis is the identification of the structural shocks, whereupon the relationship between the model variables are examined. As can be seen in equation 3, identification depends upon identifying the inverse of matrix B_0, which governs the contemporaneous relationship between the model variables. In this thesis, it is obtained applying the aforementioned Cholesky decomposition of the variance-covariance matrix of the reduced-form errors. B_0^{-1} shows how each (correlated) reduced-form shock is a linear combination of specific (uncorrelated) structural shocks. To be precise, B_0^{-1} is a lower-triangular matrix, where each element above the main diagonal is zero, and it depicts how a structural shock to each variable affects each of the models variables on impact, thus allowing for the inference of potential relationships among the variables in the model. Since the identification of B_0^{-1} is not unique with respect to the ordering of the variables, assessing the economic adequacy of the chosen ordering is crucial. In particular, as all elements above the main diagonal are zero, implying that one assumes that the variables ordered first tend to be affected by the other variables with a delay of at least one period, it would generally be reasonable to order the variables from the slowest to the fastest reacting. In summary, following the estimation of a VAR(p) model containing specific macroeconomic and yield curve variables and applying the identification strategy described above, the orthogonal shocks, based on a certain variable ordering, are used to identify the relationship between the macroeconomy and the yield curve.

Based on a standard identification set proposed by the likes of Furlanetto, Ravazzolo, and Sarferaz (2017), the empirical analysis presented in section 4 is conducted using $K = 8$ variables, where the relevant macroeconomic variables are industrial production (IP_t), inflation (π_t), and a short-term interest rate (i_t), while the financial variables include an indicator for financial stress (FS_t) and a variable representing the stock market (M_t). The variables representing the yield curve are the three factors obtained from the first step via the Nelson-Siegel decomposition (L_t, S_t, C_t). Drawing from Martins and Afonso (2010), who argue that financial variables may more prone to be affected instantaneously by shocks to the macroeconomy while the latter may react more slowly to shocks to the former, the variables are ordered from the most exogenous to the least exogenous. Thus, the ordering of vector Y_t is given by $Y_t = [IP_t,\ \pi_t,\ i_t,\ FS_t,\ L_t,\ S_t,\ C_t,\ M_t]$. This ordering is also consistent with, among others, Ang and Piazzesi (2003), who order their macro variables before the included yields in their VAR approach. While the macroeconomic variables being ordered first appears plausible given the fact that they often tend to react in a lagged manner, the stock market being ordered last broadly follows Kilian and Park (2009), assuming that the stock market reacts to shocks to the other variables contemporaneously, which seems reasonable as it is generally assumed that stocks instantaneously incorporate any new information available,[4] while, following the previously mentioned assumption that macro variables tend to react inertly, it does affect all other variables only with a delay of at least one period.

Though the selected methodology applied in the thesis has, in various forms and alterations, been applied quite often in the literature, a tremendous amount of alternative approaches is available in the economist's toolbox. A comprehensive overview of these numerous potential methodological approaches modelling the yield curve and studying it's relationship with the macroeconomy is offered in Diebold and Rudebusch (2013).

4 Empirical Results

This final Section constitutes the main body of the thesis, presenting the empirical analysis aimed at answering the research question how the macroeconomy and the yield curve are related in the United States and the Euro Area based on the methodology outlined in Section 3. Section 4.1 gives on overview of the data. Section 4.2 is concerned with the empirical results for United States, while Section 4.3 focuses on the Euro Area. Section 4.4 offers a brief comparison of the main findings in the US and the EA. Each subsection starts in a descriptive manner, focusing on the respective time series of interest, especially the estimated yield curve factors and their characteristics in relation to the macroeconomic variables, after which interpretations of the potential link between the macroeconomy and the yield curve are presented based on the resulting impulse responses obtained via a structural vector autoregression model. Lastly, block Granger causality tests are conducted as to investigate the existence of a one- or two-way relationship between the yield curve and macro variables.

[4]See, for example, Pearce and Roley (1984), Beaudry and Portier (2006), and Ormos and Vázsonyi (2011) for a discussion about the response of stock prices to economic news

4.1 Data

As to the concrete data used, the sample for the United States contains monthly data ranging from January 1976 to December 2022. All macroeconomic time series (industrial production, consumer price index, federal funds rate) have been obtained from the FRED website. The S&P 500 stock market index has been acquired via Yahoo Finance. The excess bond premium (ebp) has been chosen as the financial stress indicator, which is based on the FED note by Favara et al. (2016), and provides a measure of risk in the corporate bond market (Gilchrist and Zakrajšek, 2012). Of the highest significance for any analysis involving a Nelson-Siegel decomposition of the yield curve are the yields data used. So far, the literature — heavily focused on the US — has primarily used unsmoothed Fama and Bliss (1987) Treasury forward rates obtained via the CRSP[5] database, which are then converted to unsmoothed Fama-Bliss zero yields. Alternatively, the FED provides zero-coupon yields[6] based on the Svensson model. However, in this thesis zero-coupon US Treasury yields obtained via a novel and improved approach provided by Liu and Wu (2021) are utilized. Following Diebold, Rudebusch, and Aruoba (2006), the maturities used are 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 48, 60, 72, 84, 96, 108 and 120 months.

The data for the analysis of the Euro Area consists of monthly data, spanning from October 2004 to September 2022. Again, the bulk of the dataset has been obtained via the FRED website (industrial production, consumer price index, short-term interest rate). The Eurostoxx 50 index, representing the European stock market has been obtained via Yahoo Finance. Similar to the US, a credit risk indicator — specifically the average spread of non-financial corporation bonds relative to the German Bund yields at matched maturities — has been chosen as the financial stress variable based on the work by Gilchrist and Mojon (2014). The Euro Area yield curve data consists of spot rates derived from bonds with finite maturity denominated in EUR and issued by a euro area central government with an (issuer) rating of triple A. The data has been obtained via the ECB website and, due to somewhat limited data availability, includes yields with maturities of 3, 6, 9, 12, 24, 36, 48, 60, 72, 84, 96 and 120 months.

[5] `https://www.crsp.org/`

[6] see: `https://www.federalreserve.gov/data/nominal-yield-curve.htm`

4.2 The Yield Curve and the Macroeconomy in the United States

Figures 3-6 provide a graphical illustration of the estimated yield curve factors, how well they approximate the term structure as well as previewing their potential relationship with macroeconomic variables. Note that the shaded areas depict the months where a recession occurred in the US as identified by the National Bureau of Economic Research (NBER) Business Cycle Dating Committee.[7] In order to get an initial sense of comparability, Figure 3 depicts all three estimated yield curve factors obtained via a Nelson-Siegel decomposition based on the US Treasury yields sample spanning from January 1976 until December 2022. Among other things, one can see that the level factor, $\hat{L}_t^{US}$, has consistently been positive and well above the level of 5% up until the early 2000s. Being above 10%, the estimated level factor is fairly high during the second oil price crisis induced by the Iranian Revolution in 1979, which caused world oil prices and thus, US inflation to spike — an interesting observation that is further discussed when looking at Figure 4. Ever since the 1990s a decreasing trend in the estimated level can be observed, though the pace of the decrease has somewhat been the highest with the level being the lowest during the 2010s, whilst reaching its minimum during the COVID-19 pandemic in July 2020 — a time period marked by unconventional monetary policy such as QE and deflationary risks. As for the estimated slope ($\hat{S}_t^{US}$) and the curvature ($\hat{C}_t^{US}$) factors, both factors assume positive and negative values during the sample period, though both factors are negative for most of the time. Interestingly, the (negative) slope factor displays upward spikes and assumes positive values, i.e. 10-year yields are above 3-months yields implying an inversion of the yield curve, before almost all recessions, which is not only consistent with the findings by the yields-to-macro literature of the likes of Estrella and Hardouvelis (1991), but also discussed in more detail in Figure 5.

Figures 4-6 show the estimated factors together with their empirical proxies. These proxies are insofar relevant as they offer a first indication of the gap between the estimated coefficients and the actually realized yields (Kanjilal, 2011). Figure 4 depicts the estimated level factor, $\hat{L}_t^{US}$ and the proxy variable proposed in the literature being the arithmetic mean of the 10-year, 2-year and 3-month yield. It is apparent that the empirical proxy is fairly close to the estimated level factor, especially in the beginning of the sample, while a stronger divergence can be observed in the early 2000s as well as since the financial crisis of 2008. In recent years however, the proxy has again been close to the estimated level factor. Over the whole sample period, the correlation between the estimated level factor and the respective proxy is 96%, being in line with the findings of Diebold, Rudebusch, and Aruoba (2006), and validating the estimate as being a good representation for level factor, i.e. the long-run

[7]The recession indicator used can be found at https://fred.stlouisfed.org/series/USRECD

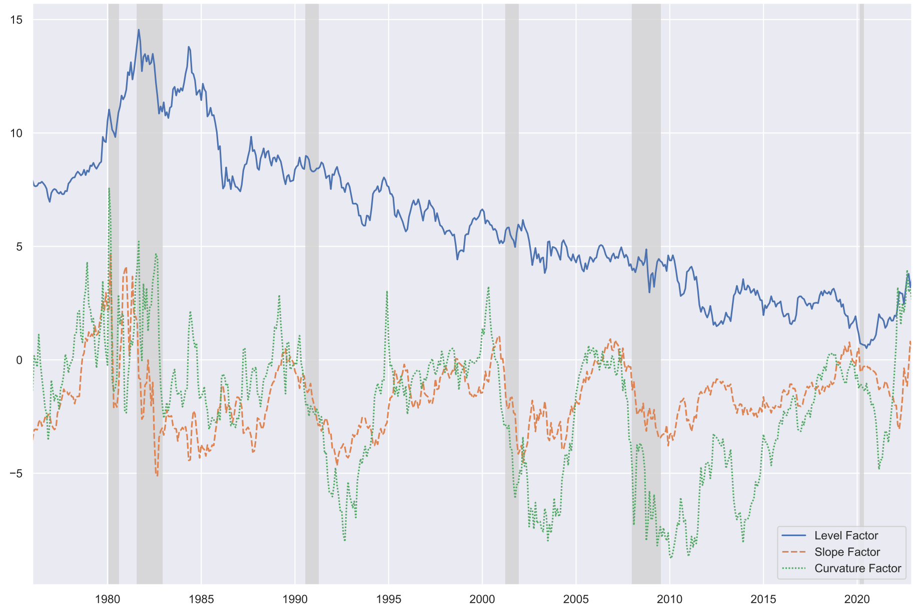

Figure 3: Estimated level, slope and curvature factor, US (in %)

component of the US Treasury yield curve. Since it is the first indication of a link between the macroeconomy and the yield curve, a highly interesting observation for the task at hand can also be drawn when comparing the evolution of the level factor with the inflation rate over time. From the Fisher equation one can derive how nominal interest rates and inflation expectations could be linked. Based on Fisher (1930), one would expect that nominal interest rates move one-to-one with a change in expected inflation, with the real interest rate being unaffected. In order to study this proposition, Figure 4 also includes the year-on-year change in the CPI depicted by the dotted green line. Though this inflation measure is concerned with actual and not expected inflation, one can see that an increase in the inflation rate is oftentimes accompanied by a surging level factor. For example, the spiking inflation rate during the second oil crisis beginning in 1979 is followed by a tremendous increase in the level factor — both variables reaching levels merely short of 15% — providing a first indication that the inflation rate is indeed linked with the long-run factor of the yield curve. When looking at the recent period of inflationary pressures induced by supply bottlenecks during the COVID-19 pandemic in 2021 as well as the Russian aggression in Ukraine since 2022, one can see that again the level factor, which has certainly been flanked by increasing interest rates through monetary tightening by the Federal Reserve System beginning in March 2022, has moved in accordance with actual inflation, though not rising as sharply as the inflation rate did. Overall, the

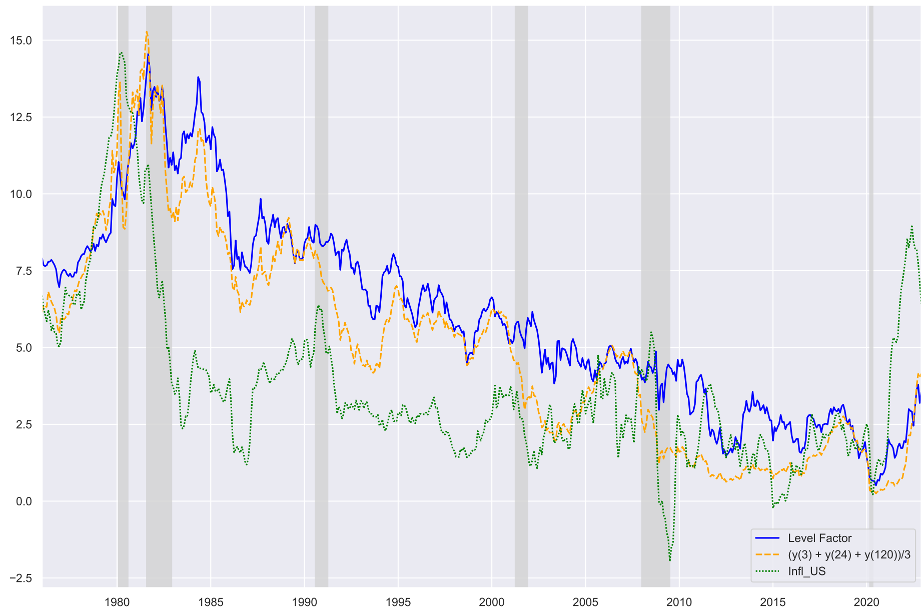

Figure 4: Level factor, empirical proxy and inflation, US (in %)

estimated level factor and inflation exhibit a rather strong co-movement in the US. In fact, the correlation between $\hat{L}_t^{US}$ and inflation over the sample period is 55% and significant[8], a finding that is consistent with the interpretation of the level factor as being related to inflation expectations, as described in, among others, Dewachter and Lyrio (2006), Rudebusch and Wu (2008), and Diebold, Rudebusch, and Aruoba (2006).

Looking at Figure 5, one can see that the estimated slope factor, $\hat{S}_t^{US}$ is extremely close to its empirical proxy being the (negative) slope of the yield curve, i.e. the difference between the 3-month and 10-year yields. In fact, the correlation is 95% and thus, not only significant but also strikingly high. As mentioned before, the slope factor is assumed to be correlated, indeed even able to predict economic activity based on an abundance of literature. Thus, to again get a glimpse of a possible link between the macroeconomy and the yield curve — here represented by the slope factor — Figure 5 also depicts economic activity in the form of the year-on-year growth rate of industrial production over time. Evidently, there is some co-movement between the slope and industrial production, where most economic downturns are

[8]From hereon, a significance level of 5% is postulated with regards to statistical hypothesis testing

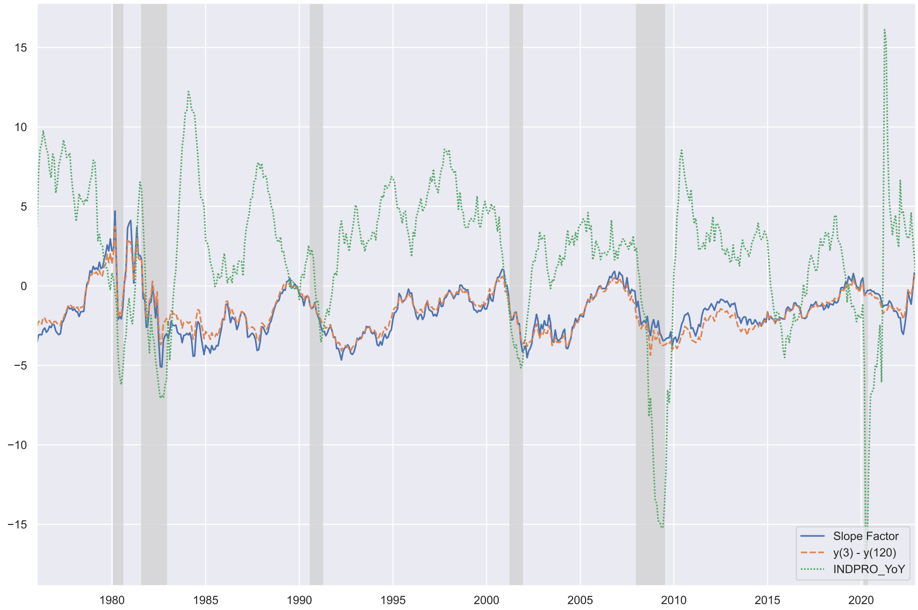

Figure 5: Slope factor and empirical proxy, US (in %)

preceded by an upward spike in the term spread. Though the correlation of around -3% is neither strong nor significant, the pattern revealed corroborates the findings related to the yields-to macro literature outlined in Section 2 to some extent and again strengthens the case of a link between the yield curve and the macroeconomy. Similarly in Figure 6, with a correlation of 93%, the curvature factor tends to be somewhat close to its proxy, where they generally have similar trends over time, though it unambiguously has a very high volatility relative to it's proxy variable.

In summary, on the one hand the observations described above tend to validate the indication that the estimated Nelson-Siegel factors accurately represent the yield curve and are thus, fitted for studying the relationship between the macroeconomy and the term structure. On the other hand, Figures 4 and 5 have also offered pre-emptive evidence confirming that there indeed seems to be a relationship consistent with economic theory as well as the literature, namely that the level factor seems to be an accurate representation of the bond market's long-run inflation gauge, as well as an increasing slope factor potentially indicating an upcoming recession. Consequently, the next step involves analysing macroeconomic and yield curve variables together in a comprehensive structural VAR framework[9] outlined in Section

[9]Note that the VAR models in this thesis are estimated via Ordinary Least Squares (OLS)

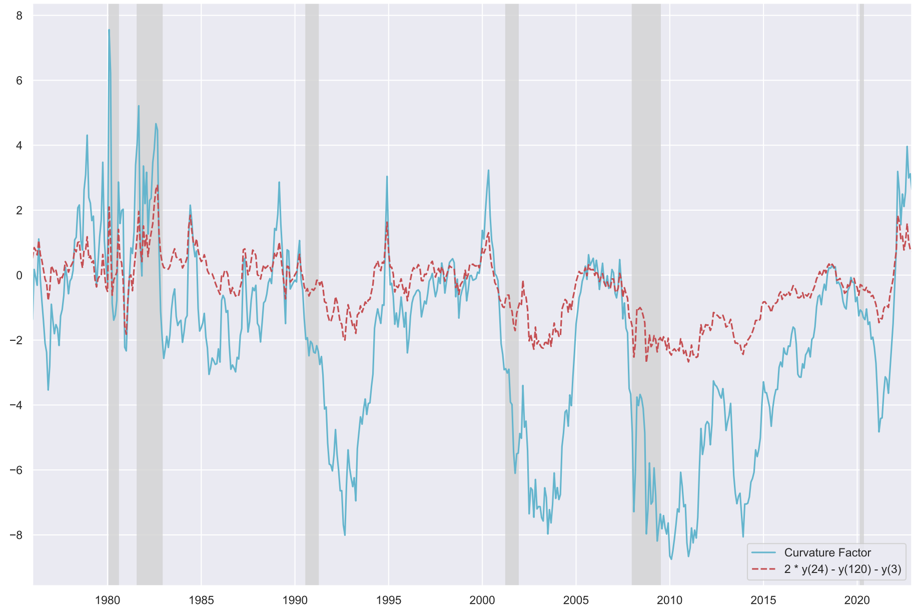

Figure 6: Curvature factor and empirical proxy, US (in %)

3. However, before fitting a VAR model, it is first important to understand the nature of the variables involved. Thus, Table 5 shows the results of an Augmented Dickey-Fuller (ADF) test of each variable included in the model, testing whether it is non-stationary, i.e. it possesses a unit root at the 5% significance level. While inflation (π_t^{US}), the federal funds rate (i_t^{US}), the level ($\hat{L}_t^{US}$) and curvature factor ($\hat{C}_t^{US}$) are non-stationary, one can reject the null hypothesis of the existence of a unit root at the 5% level for all remaining model variables. This is partly not surprising given the fact that the year-on-year growth rates for industrial production and stock prices are used, which results in detrended time-series. Without the price level spikes of the 1980s and the idiosyncratic shocks of the 2020s, inflation would be stationary.[10] Taking the first (second) differences of all non-stationary variables would result in stationary time series, though due to consistency considerations as well as previous methodologies used in the literature, these time series are included levels (first differences). While Morales (2010), among others, argues that the order of the estimated model should take into account parsimony reasons and thus, limit the lag order to a minimum, authors such as Evans and Marshall (1998), Ang and Piazzesi (2003) and Ang, Piazzesi, and Wei (2006) implement their modelling

[10]Conducting an ADF test for the period from January 1990 until December 2019 results in the rejection of the null hypothesis of the existence of a unit root (p-value = 0.0025)

Lag	Log-Likelihood	AIC	BIC	HQIC
$p = 1$	-4270.0608	-7.5475	-7.0008	-7.3342
$p = 2$	-4072.6743	-7.9874	-6.9533	-7.5840
$p = 3$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 4$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 5$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 6$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 7$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 8$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 9$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 10$	-3954.3057	-8.1520	-6.6293	-7.5580
$p = 11$	-3356.5766	-8.2498	-2.7697	-6.1105
$p = 12$	-3272.7619	-8.2946	-2.3137	-5.9596

Table 1: Information criteria VAR(p) model, US

strategy with up to 12 lags. Accordingly, Table 1 shows the different information criteria for a VAR model with an autoregressive order of up to 12 lags. Seemingly, the log-likelihood as well as the Akaike information criterion (AIC) would select an order of $p = 12$, while the Bayesian (BIC) and Hannan-Quinn (HQIC) information criteria suggest using a lag length of 1 and 2, respectively. Therefore, to take both parsimony reasons as well as the limited frequentist modelling strategy into account, a lag length of 6 is chosen.

Since the aim of this thesis is to understand the dynamic interactions between the yield curve and the macroeconomy in the United States, Figure 7 depicts the orthogonal impulse responses to a one unit shock in each of the model's variables over a three year period (36 months) with 90% confidence intervals. Each row shows the response of a certain variable i to a specific structural shock of variable j, where each column displays to which variable j the respective shock occurred. For example, the second row shows the responses of inflation (π_t^{US}) to various structural shocks to the model variables, while the third column illustrates the responses of each variable to a structural monetary policy shock represented by the short-term interest rate (i_t^{US}). With this in mind, there are four types of impulse responses to consider: macro-to-macro, macro-to-yields, yields-to-macro and yields-to-yields.

As a first assessment of validity, the macro-to-macro impulse responses are considered. It is reassuring that the results seem to broadly match those of similar small scale macro models oftentimes used in the literature (e.g. Galí (1992), Stock and Watson (2001)). Specifically, a shock to industrial production, i.e. an aggregate demand shock, increases both inflation (second row, first column) and the short-term interest rate (third row, first column), while an inflation shock decreases aggregate demand over time. The federal funds rate (i_t^{US}) increases both on impact as well as over time in response to a positive inflation shock, which is not only consistent with economic theory, but, given the dual mandate of the Fed, also with real-world central bank behavior. The last macro-to-macro shock to consider is a monetary policy shock (third column). Since the short-term restrictions described in Section 3 are based on the assumption that both industrial production and inflation react with a certain time lag, both variables do not react on impact, but over time — as one would expect based on economic reasoning — industrial production as well as inflation decrease as a response to a surprise increase in the short-term rate, where the decrease of inflation is more persistent, while industrial production decreases more strongly during the first year. Interestingly, when comparing the response of inflation to a monetary policy shock given different autoregressive orders, the well known "price puzzle", that is a positive response of inflation to a monetary tightening, occurs in both Figures 7 and 14 depicting the IRFs based on a higher autoregressive order, while inflation steadily decreases over time in Figure 13, where the IRFs are based on an order of $p = 1$.

Examining the first direction of the link between the macroeconomy and the yield curve, i.e., yield curve responses to macro shocks, offers some interesting insights. For example, an aggregate demand shock increases the level factor, which, when keeping in mind the interpretation of the level factor as the bond's market long-run inflation expectation - via the Fisher effect - seems reasonable as higher aggregate demand should generally lead agents to expect a higher future price level. Similarly, the slope factor increases after an aggregate demand shock over time, implying that the short-end of the yield curve rises relative to the long-end. Again, this is in line with standard monetary policy responses to surprises in aggregate demand since bond investors would expect central banks to increase interest rates in the near term as they anticipate higher inflation due to the aggregate demand shock, likely pushing up short-run yields relative to the long-end of the term structure (Diebold, Rudebusch, and Aruoba, 2006). A similar response can be observed when looking at aggregate supply shocks (inflation shocks). Specifically, the level, curvature as well as the slope factor increase after a surprise increase in US inflation, though notably, the slope factor initially decreases in the first few months after which it increases over time. The former result can be explained via the aforementioned Fisher effect, where the bond market likely expects higher future inflation when facing a surprise upward tilt in the current inflation rate leading to an increase in yields. This increase in the level factor would correspond to the assumption that inflation expectations are not firmly anchored (Diebold, Rudebusch, and Aruoba, 2006). The latter effect is again linked to monetary policy, where higher short-term rates are priced in by investors due to present and likely future expected price level increases, leading to a more negatively sloped yield curve. Interestingly, both phenomena have occurred only recently during the last two years, where inflationary pressures induced by

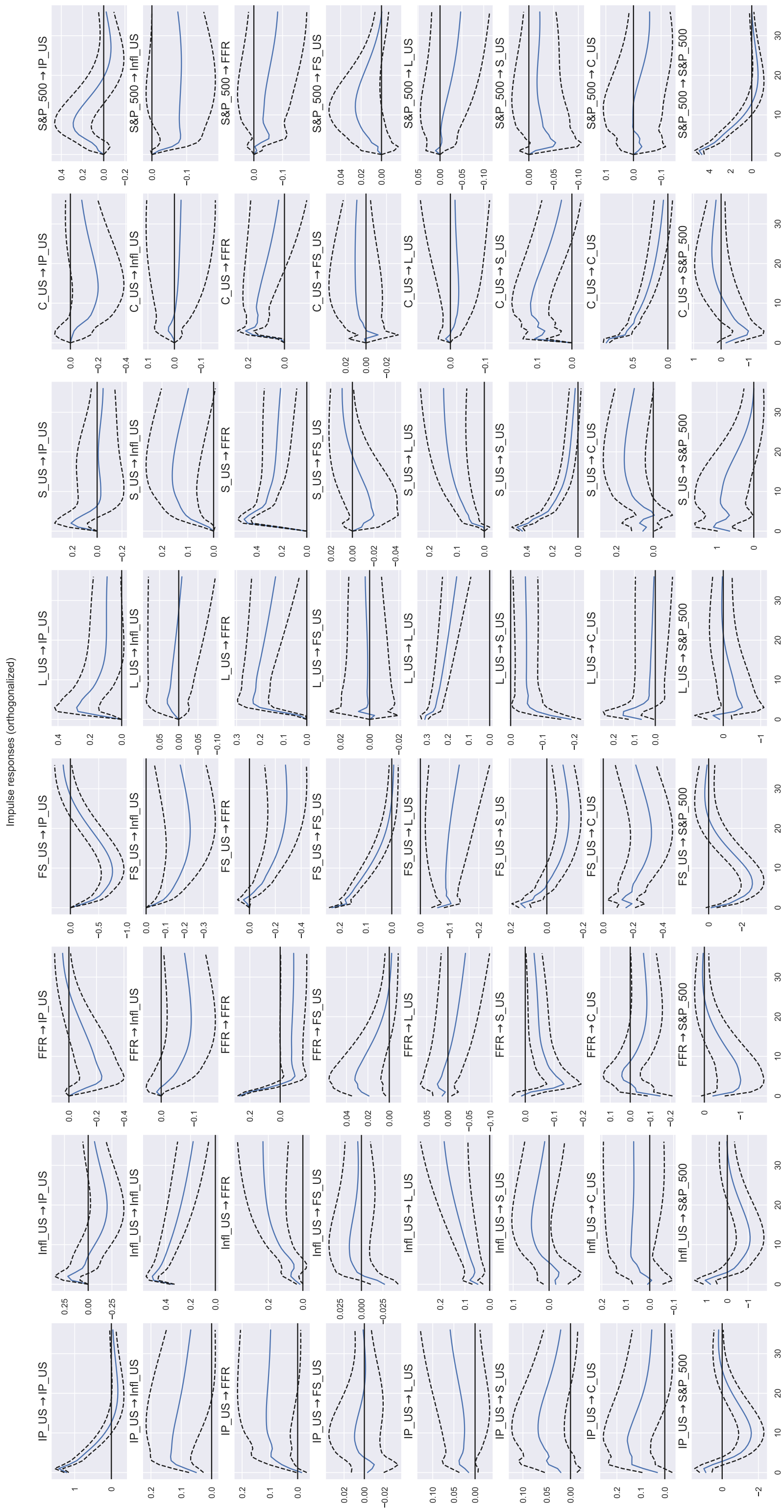

Figure 7: Impulse Responses SVAR(6), US

the war in Ukraine led to significant increases in US yields due to the markets expectation of an imminent monetary tightening by the FED, while the yield curve inverted as short-end yields exceeded long-end yields in anticipation of an upcoming recession. The last macro-to-yields shock to consider is a monetary policy shock. As well as the curvature factor responding by a decrease over time, the level factor marginally increases on impact but then decreases after about a year in response to a surprise increase in the federal funds rate (third column). In this context, contrasting explanations regarding the level factor's response to a monetary policy shock are offered by the literature. Given a central bank has a high degree of credibility and transparency, a surprise monetary tightening could indicate a lower inflation target and thus, induce bond investors to revise their inflation expectations downwards, potentially lowering the level factor, while a surprise tightening could also signal that a central bank is concerned about an overheating economy and an overshooting inflation rate, which would likely result in higher expected inflation and thus, an increasing level factor (Diebold, Rudebusch, and Aruoba, 2006). Apparently, the former effect has dominated the latter over the sample period, which does not seem implausible given the high credibility of the Fed.

The other direction of causality to consider is the yields-to-macro channel. The short-term interest rate increases after a shock to both the long-run level factor, as well as the slope factor, where its response to the latter is strikingly high, not only confirming that there is a close connection between the monetary policy instrument and the short-run factor of the yield curve, but also being consistent with the finding by Evans and Marshall (1998), i.e. that monetary policy primarily affects short-term interest rates with longer-term rates being affected only marginally. Again considering the level factor as depicting agents long-run inflation expectations, it could be argued that monetary authorities increase their policy rate in order to counteract the unanticipated increase in inflation expectations and prevent them from becoming unanchored. In this context, two distinct explanations are offered by the literature. On the one hand, the FED might respond to current yields when setting the short-term rate, whilst on the other hand, market yields very likely respond to new information regarding the macroeconomy in anticipation of monetary policy decisions, and, given the ordinary six week cycles of monetary policy decisions, shifts in fixed-income markets presumably precede central bank actions (Diebold, Rudebusch, and Aruoba, 2006; Morales, 2010). This would, for example, lead to short-end yields to increase in anticipation of an imminent monetary policy tightening due to a surprise increase in aggregate demand. Notably, the federal funds rate also responds with an increase to a shock in the curvature factor, though not by the same order of magnitude as compared to a shock to the yield curve slope. Another compelling case to consider is that a shock to the level factor increases aggregate demand. This is insofar relevant from the economists lens when once again keeping in mind the level factors' interpretation as a proxy for inflation expectations. In this case, an increase in inflation expectations lowers the ex-ante real interest rate, $i_t^{US} - \hat{L}_t^{US}$, leading to a surge in economic activity - a finding that is consistent with standard DSGE models. Likewise, a shock to the level factor leads to an increase in inflation, which is plausible since a decreasing ex-ante real interest rate should lead to rising aggregate demand, which indeed is the case based on the impulse response in the first row and fifth column - and thus, ceteris paribus, inflation. Nonetheless, the response of inflation to a level factor shock is rather muted. Interestingly, considering the IRFs based on a VAR(12) in Figure 14, the response of inflation to a level factor shock is more pronounced an more persistent. In contrast, some rather implausible responses raise questions about the validity of the yields-to-macro results. For example, the response of industrial production to a surprise increase in the yield curve slope does contradict previous findings in the literature. Specifically, an increase in the slope - equivalent to a flattening and potentially inversion of the yield curve - is generally associated with an imminent recession rather than an economic boom. Similarly, assuming an impending recession, one would anticipate inflation to decrease over time in response to a shock to the slope factor. Again considering Figure 14, a shock to the slope factor indeed results in an economic contraction after about a year, though the same response cannot be observed for inflation. Based on these partly dubious results regarding the slope one could argue that these findings confirm the conclusions of Ang, Piazzesi, and Wei (2006), where the short-term interest rate dominates the slope of the yield curve when predicting economic activity, at least when comparing the plausibility of the impulse responses for shocks to the short-term interest rate vis-a-vis shocks to the slope in Figure 7. Furthermore, it could be argued that the frequentist modelling strategy based on OLS estimates certainly has some limitations and likely leads to partially improbable results. In this context, it also has to be noted that the yields-to macro responses generally have wider confidence intervals. Hence, it seems that there is more uncertainty involved in the macro responses to yield curve shocks, whereas there is a stronger evidence for the macro-to-yields channel, not only because those responses are associated with relatively less uncertainty, but they are also broadly consistent with economic theory as well as previous results in the related literature.

The remaining impulse responses to consider are the yields-to-yields shocks. Apart from the high persistence in the level and slope factor, some noteworthy observations include the slope factors response to a level factor shock. Consistent with the findings of Diebold, Rudebusch, and Aruoba (2006), a surprise increase in the level factor, i.e. long-run inflation expectations, is associated with loose monetary policy conditions represented by a lowering of the short-end of the yield curve relative to the long-end, synonymous with a steepening of the yield curve, i.e., a decrease in the slope factor. Similarly, a surprise increase in the slope factor, possibly as anticipation to a monetary tightening, is associated with an increase of the level factor, corresponding to higher future inflation expectations.

	t-statistic	Critical value	p-value
Macro-to-Yields	78.3778	40.1132	0.0000
Yields-to-Macro	1129.6180	40.1132	0.0000

Table 2: Block Granger causality tests, US

Finally, the link between the yield curve factors and the macroeconomic variables are assessed using block Granger causality tests, where one can test if a set of variables Granger cause another set of variables in the model. Conveniently, this method enables to indicatively determine whether there is a one- or bi-directional relationship present, e.g. testing whether solely a set macro variables Granger cause the yield curve factors or if both the macro variables do Granger cause and are Granger caused by the yield curve factors. In the present setting, the macro-to-yields test examines whether the set of macro variables in the model (IP_t^{US}, π_t^{US}, i_t^{US}) do Granger cause the estimated yield curve factors ($\hat{L}_t^{US}$, $\hat{S}_t^{US}$, $\hat{C}_t^{US}$), whilst the yields-to-macro test evaluates the presence of a Granger causality in reverse order, namely, if the yield curve factors Granger cause the set of macro variables. Based on Table 2, depicting the resulting block Granger causality tests, one can conclude that there seems to be a bi-directional link present in the United States, where both macroeconomic variables seem to contain useful information regarding the behavior of the yield curve and, vice versa, the yield curve seems to affect macroeconomic fluctuations.

4.3 The Yield Curve and the Macroeconomy in the Euro Area

Though, starting in January 2004, the sample period is markedly smaller compared to that of the United States, the analysis of the Euro Area nevertheless reveals some further interesting insights into the relationship between the yield curve and the economy. Figures 8-11 give an initial overview, where the shaded bars represent months where a recession occurred as dated by the CEPR-EABCN Euro Area Business Cycle Dating Committee.[11] Again Figure 8 offers a comparison between all three estimated Nelson-Siegel factors over time. The level factor has been positive up until 2016, while also exhibiting a decreasing trend for most of the time, especially since 2012, a time period, as mentioned before, marked by QE, negative interest rates, and in the case of the Euro Area, the European debt crisis. Since the start of 2022, where residual inflationary pressures due to the COVID-19 pan-

[11] The corresponding recession dates can be found here `https://eabcn.org/dbc/peaksandtroughs/chronology-euro-area-business-cycles`

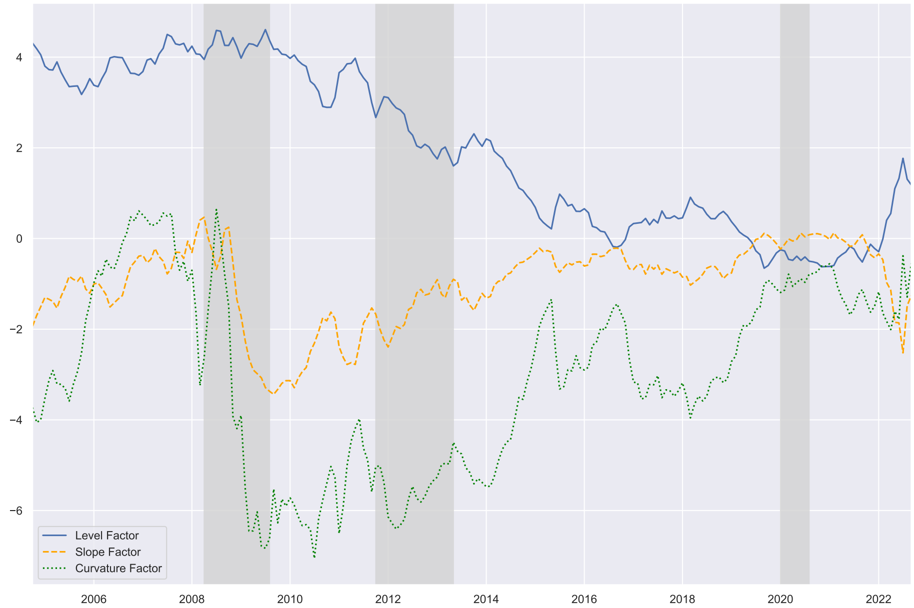

Figure 8: Estimated level, slope and curvature factor, EA (in %)

demic as well a sharp increase in prices induced by soaring energy prices due to the conflict in Ukraine severely affected the European economy, the level factor has increased quite strongly, surpassing the 2% mark — an interesting observation that is not only in line with the above mentioned Fisher effect regarding the relationship between the level effect and inflation, but also best seen in Figure 9. Evidently, the curvature factor has the highest volatility, especially due to the spike in 2008, which could be due to an idiosyncratic shock in the form of the financial crisis, but could also be attributed to the fact that the Euro Area yields are based on a rather diverse pool of issuers with possible unobserved heterogeneity, which could potentially have confounding effects when using the Nelson-Siegel model.

Once more, in order to get an indication of how well the factor estimates represent the yield curve, Figures 9-11 display the estimated factors, $\hat{L}_t^{EA}$, $\hat{S}_t^{EA}$, $\hat{C}_t^{EA}$, along with their respective empirical proxies. All three estimates exhibit a very strong and significant correlation with their proxies ranging from 92% ($\hat{L}_t^{EA}$) to 96% ($\hat{C}_t^{EA}$), which underlines the suitability of the estimates as accurately representing the level, slope and curvature of the Euro Area yield curve. The correlation between inflation and the level factor in the Euro Area, though not only being significant, is 17% during the sample period, which certainly is consistent with the Fisher effect and the interpretation of the level factor as being an approximation for the expected infla-

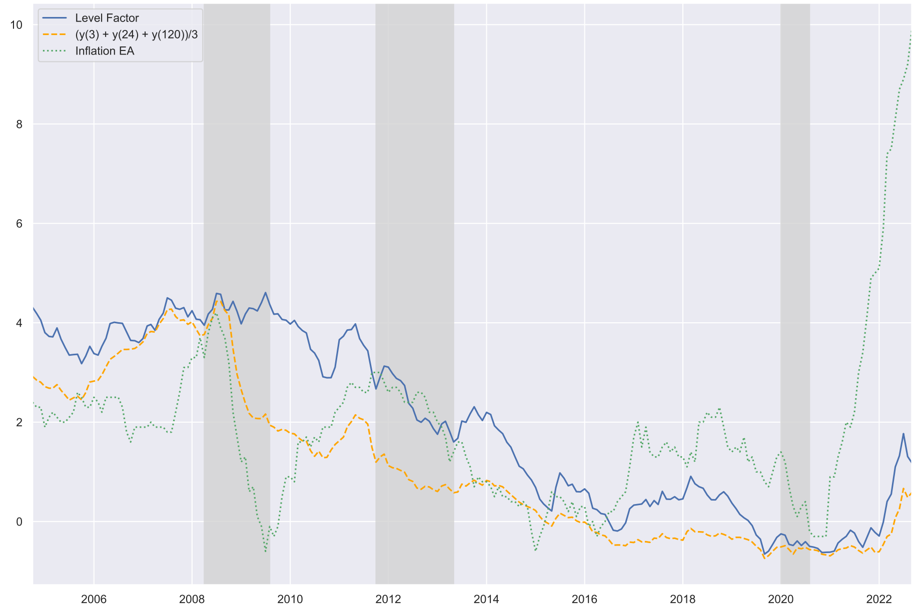

Figure 9: Level factor, empirical proxy and inflation, EA (in %)

tion rate, considering the small sample period and the occurrence of various distinct idiosyncratic shocks mentioned before. Apart from the estimated slope factor and it's proxy variable, Figure 10 also includes Euro Area industrial production representing economic activity. The first thing that stands out is the very high variability of industrial production, especially during the COVID-19 pandemic starting in early 2020, ranging from -19,91% to 23,90%. Though the recession following the financial crisis of 2007/08 was preceded by an upward trend and the estimated slope factor even assuming positive values shortly before the contraction — being consistent with the yields-to-macro literature — the number of economic downturns simply is too small during the short sample to infer any substantial conclusions regarding the validity of the relationship between the term spread and economic activity in the Euro Area. In short, Figures 8-11 show that the obtained estimates are very close to their respective proxy variables, and are thus well suited to represent the Euro Area yield curve. Nevertheless, they have also indicated that the limited sample period of 216 months marked by various distinct exogenous shocks such as he financial crisis of 2007/08, the European debt crisis starting in 2010, the COVID-19 pandemic starting in 2020 and the ongoing war in Ukraine since February 2022 likely stretch the rather simplistic approach used in this thesis to its limits and likely impedes ones ability to draw viable conclusions when examining the interactions between macro variables and the term structure.

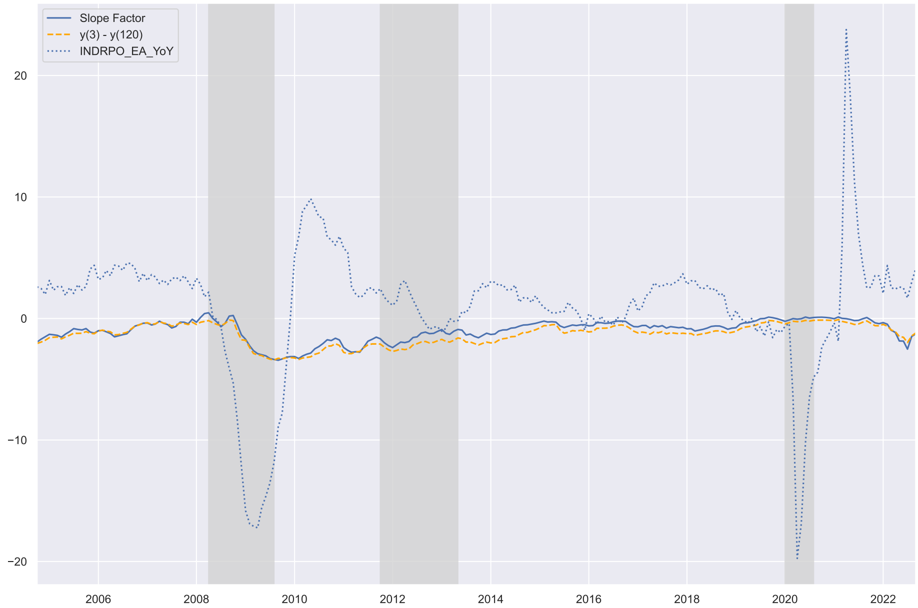

Figure 10: Slope factor and empirical proxy, EA (in %)

Nonetheless, in order to study the dynamics between the yield curve and the macroeconomy in the Euro Area, orthogonalized impulse responses have been obtained using the modelling strategy outlined in Section 3. In order to examine the stationary of the time series involved, Table 6 shows the results of respective ADF tests for each variable, testing the presence of a unit root at the 5% significance level. The inflation rate in the Euro Area is not stationary, which is not surprising since the years after the financial crisis of 2007/08 have been marked by a decreasing trend in inflation, while inflation has surged since the start of 2022 due to the ongoing Ukraine war. Similarly, the short-term Euro Area interest rate — the 3-month interbank rate — is also non-stationary. All three yield curve factors do possess a unit root. Equivalently to the model that has been fitted for the US data, a VAR of order $p = 6$ has been chosen for the Euro Area. Table 3 shows the different information criteria as well as the log-likelihood for specific lag orders of $p = 1, \ldots, 12$. While the BIC and HQIC would select an order of 1 and 2 lags, respectively, the AIC as well as the log-likelihood suggest an estimation with 12 lags. Again, as to balance between a parsimonious estimation as well as maximizing the informative content given a frequentist modelling strategy, a lag lengths of $p = 6$ has been chosen.

Now, taking Figure 12 into consideration, depicting the orthogonal responses to a one unit impulse of each variable involved in the model over a period of 36 month

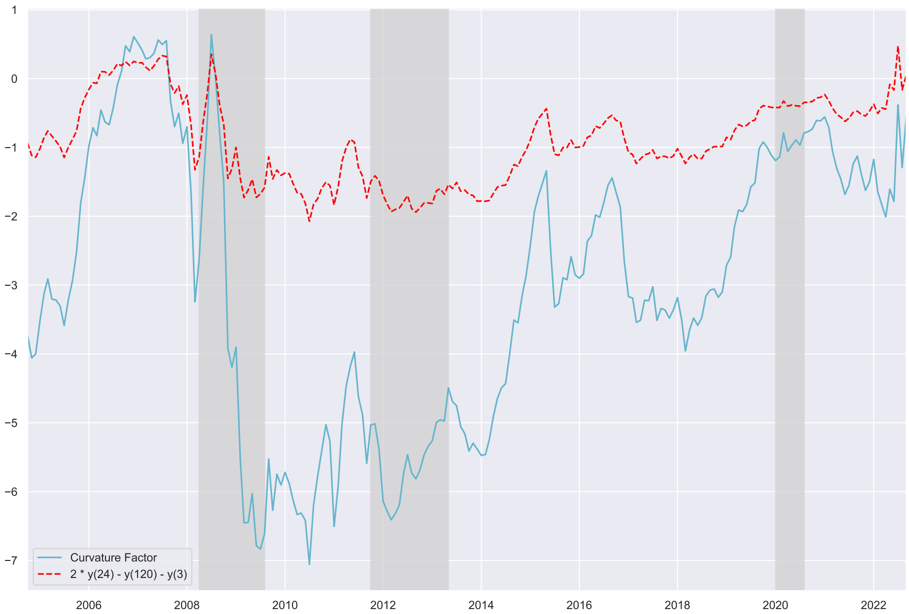

Figure 11: Curvature factor and empirical proxy, EA (in %)

with 90% confidence bands, there are again four different types of dynamics to evaluate. Among those, the macro-to-macro responses seem to be consistent with standard impulse responses from macro-only models. An aggregate demand shock - a shock to IP_t^{EA} - is associated with an increase in inflation (π_t^{EA}) and the short-term interest rate (i_t^{EA}), though each response is rather small. Given the impulse responses in Figure 16 the increase in inflation is marginally more pronounced while i_t^{EA} only increases given a shock to industrial production after about a year. An aggregate supply shock in the form of an increasing inflation rate decreases industrial production after about 8 months and leads to an increase in the interest rate, thus, being in accordance with a monetary policy response to surprise increases in prices. Again, these responses are rather limited, but nonetheless consistent with economic theory. Considering the case of a surprise monetary tightening results in both a decrease in aggregate demand and prices, where the former persistently decreases, while latter initially increases slightly but then strongly decreases, especially when considering the $p = 12$ case in Figure 16, indicating that the effects of monetary policy potentially affect aggregate demand after a certain time lag.

Continuing with the macro-to-yields responses, an unexpected increase in both aggregate demand as well as aggregate supply induces an increase in the yield curve level. Here again, since one likely expects inflation to rise in the future after a

Lag	Log-Likelihood	AIC	BIC	HQIC
$p = 1$	-747.0395	-15.0840	-13.9553	-14.6280
$p = 2$	-604.0538	-15.7866	-13.6475	-14.9222
$p = 3$	-535.1140	-15.8005	-12.6444	-14.5250
$p = 4$	-466.9773	-15.8070	-11.6271	-14.1176
$p = 5$	-466.9773	-15.8070	-11.6271	-14.1176
$p = 6$	-466.9773	-15.8070	-11.6271	-14.1176
$p = 7$	-466.9773	-15.8070	-11.6271	-14.1176
$p = 8$	-466.9773	-15.8070	-11.6271	-14.1176
$p = 9$	-466.9773	-15.8070	-11.6271	-14.1176
$p = 10$	-466.9773	-15.8070	-11.6271	-14.1176
$p = 11$	8.2485	-15.8371	-4.2958	-11.1689
$p = 12$	82.5094	-15.9041	-3.2822	-10.7983

Table 3: Information criteria VAR(p) model, EA

surge in either aggregate demand or prices, the interpretation of the level factor as the long-run gauge of inflation proves convenient. Analogously, the slope factor somewhat increases in the first few months as a response to innovations in economic activity over time, which would again be consistent with a monetary policy response to an increase in aggregate demand, increasing the short-term interest rate and thus, the short-end of the yield curve relative to the long-end. However, the response of the slope factor is rather small and fluctuates around the zero line considering both the 6 lag and 12 lag case. An aggregate demand as well as an aggregate supply shock both lead to a decrease in the medium-term curvature factor. As mentioned in Section 4.2, the response of the yield curve level to a monetary policy shock can have two distinct interpretations. Either the level factor increases after a surprise monetary tightening due to agents assuming that monetary policy authorities fear an overheating economy and thus, adjust their inflation expectations upwards, or, in light of high credibility of a central bank, the level factor decreases since the tightening could imply a lower inflation target (Diebold, Rudebusch, and Aruoba, 2006). Seemingly, monetary authorities posses a high degree of credibility in the Euro Area since the level factor decreases after an innovation in i_t^{EA}. The slope factor increases on impact and over time after a surprise increase in the interest rate suggesting that the short-term factor of the yield curve seems to be intricately linked to the monetary policy instrument. A similar response can be observed from the curvature factor, which increases on impact after a monetary policy shock.

Coming to the yields-to-macro responses, a shock to the level factor induces aggregate demand as well as aggregate supply to increase. Once more, this is consistent with the notion of the yield curve level as representing long-run inflation expec-

	t-statistic	Critical value	p-value
Macro-to-Yields	119.9711	50.9985	0.0000
Yields-to-Macro	60.4081	50.9985	0.0066

Table 4: Block Granger causality tests, EA

tations, since one would assume that aggregate demand as well as prices would increase given a surprise increase in the ex-ante real interest rate, $i_t^{EA} - \hat{L}_t^{EA}$. The short-run interest rate also increases after a shock to the level factor, which is in accordance with a monetary policy reaction function such as the Taylor rule, where an increase of inflation expectations should lead to a higher nominal interest rate. Interestingly, economic activity decreases after the yield curve becomes less steep when considering all three different autoregressive orders depicted by Figures 12, 15 and 16, where the economic contraction occurs after 1-12 months. This finding is consistent with the yields-to-macro literature in the manner of Estrella and Hardouvelis (1991). Suitably, inflation decreases after a shock to the slope factor, which would fit the narrative that a flattening and potential inversion of the slope of the yield curve is a leading indicator for an upcoming recession and thus, through decreasing aggregate demand, a fall in the price level. Beyond this, the short-term interest rate slightly decreases after a flattening of the yield curve, which is yet again consistent with the notion of the slope of the term spread indicating an economic contraction, where one would expect a resulting monetary expansion to counteract said downturn. The macro variables respond quite mixed to curvature factor shocks, having no significant impact on industrial production and inflation, though notably it induces a persistent increase of the short-term interest rate over the whole three years. Overall, the yields-to-macro responses in the Euro Area do conform quite well with economic theory as well as previous findings in the literature.

Taking into account the yields-to-yields responses, the slope factor seems to only marginally affect the other level factor, while a shock to the long-run factor decreases both the slope and curvature factor, respectively. The surprise increase in the medium-term curvature factor leads to a decrease in the slope, whereas the yield curve level is not affected.

Finally, to test for the existence of a one or bi-directional relationship, Table 4 shows two block Granger causality tests based on the estimation results. Once again, the macro-to-yields block tests whether the macro variables (IP_t^{EA}, π_t^{EA}, i_t^{EA}) Granger cause the yield curve variables ($\hat{L}_t^{EA}$, $\hat{S}_t^{EA}$, $\hat{C}_t^{EA}$), while the yields-to-macro tests the Granger causality in the opposite direction. Apparently, the null hypothesis of no Granger causality present can be rejected for both sets of variables, leading to the conclusion that again a bi-directional link between the macroeconomy and the yield curve is present in the Euro Area. However, when considering the rather implausible

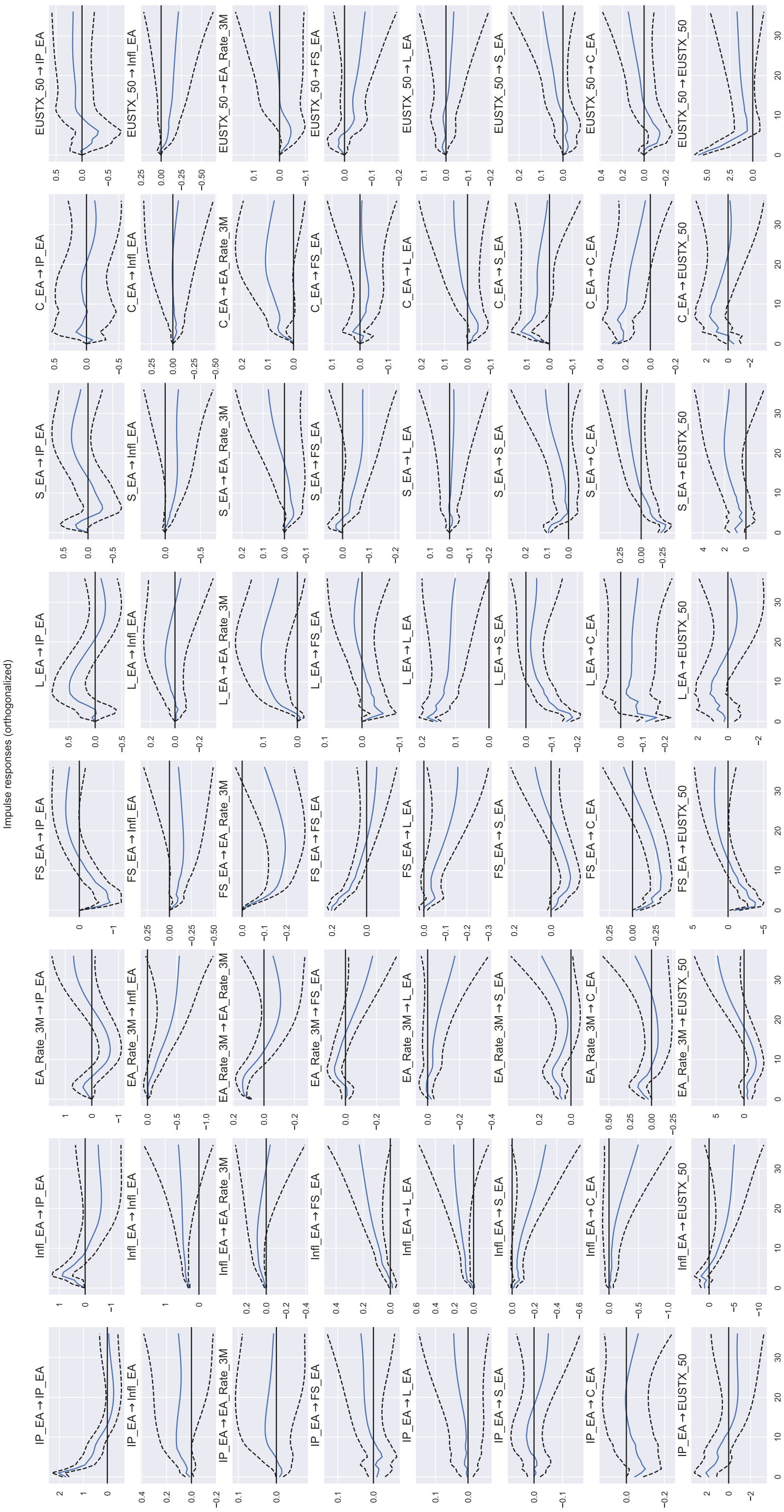

Figure 12: Impulse Responses SVAR(6), EA

and/or insignificant yields-to-macro responses in in Figure 12, this conclusion seems unconvincing. As was the case in the United States, the responses concerned with the macro-to-yields channel in the Euro Area seem more credible and consistent with the literature.

4.4 Comparing the United States and the Euro Area

While the level factor has been positive over the whole sample in the US, the level factor has been positive and negative during the whole sample period in the EA, while also exhibiting a decreasing trend for most of the time, especially since the mid 2010s, a period, as mentioned before, marked by QE, negative interest rates, and in the case of the Euro Area, the European debt crisis. Hence, while the hypothesis of monetary policy inertia in the context of G. D. Rudebusch (2005) seems to be rejected for the United States, the ECB seems to act more sluggishly based on the high persistence of the short-term rate even when controlling for the term structure via the Nelson-Siegel factors. In contrast to the United States, all three yield curve factors do possess a unit root and are thus, not stationary. Seemingly, neither in the United States, nor in the Euro area inflation expectations are firmly anchored since in both economies an unanticipated upward tilt in prices leads to inflation expectations (the level factor) to increase. Interestingly, though a positive response of the slope factor in the US can be observed with regards to a price shock, the yield curve slope in the Euro Area seems to respond with a decrease to inflation shocks. As mentioned in Section 4.2, the response of the yield curve level to a monetary policy shock can have two distinct interpretations. Either the level factor increases after a surprise monetary tightening due to agents assuming that monetary policy authorities fear an overheating economy and thus, adjust their inflation expectations upwards, or, in light of high credibility of a central bank, the level factor decreases since the tightening could imply a lower inflation target (Diebold, Rudebusch, and Aruoba, 2006). Whereas the latter effect dominated in the United States, i.e. the yield curve level decreased after an upward shift in the short-term rate, pointing to a high credibility of the FED, the level factor responds with an increase to a monetary policy tightening in the Euro Area, indicating that the former effect prevails. As was the case in the United States, the slope factor increases on impact after a surprise increase in the interest rate suggesting that the short-term factor of the yield curve seems to be intricately linked to the monetary policy instrument. However, by order of magnitude, the response of the slope factor to a monetary policy shock is markedly higher in the United States than in the Euro Area. While a shock to S increases inflation in the US, it decreases in the EA. Industrial production EA increases after a shock to the level factor, which is consistent with the finding in the United States that a surprise jump in expected inflation leading to a decrease in the ex-ante real interest rate, $i_t^{EA} - \hat{L}_t^{EA}$, results in an economic expansion. Inflation decreases in the

EA after a shock to the slope factor being in line with the yields-to-macro literature, while this is not the case in the US.

5 Conclusion

To summarize, this thesis has investigated how the yield curve and the macroeconomy are related in the United States as well as the Euro Area, especially focusing on the question, if there is a one or bi-directional link. By using a two step approach similar to Diebold, Rudebusch, and Aruoba (2006), first modelling the yield curve using the Nelson-Siegel model to obtain a level, slope and curvature factor and subsequently including said factors in a VAR model containing various other macroeconomic as well as financial variables, the resulting structural shocks have given an indication of said relationship.

A possible extension of this thesis would be to actually use the estimated slope factors in a probabilistic setting like the one proposed by Estrella and Hardouvelis (1991) and see if said factors, being an approximation of the term spread, are able to correctly predict the onset of past recessions - a finding that would be consistent with the literature. Furthermore, testing the performance in yield (curve) forecasting of a general Nelson-Siegel model versus the extended model including macro variables used in this thesis could be further enlightening in regards to the usefulness of a yields-macro model.

References

Altavilla, Carlo et al. (2019). "Measuring euro area monetary policy". In: *Journal of Monetary Economics* 108, pp. 162–179. ISSN: 0304-3932.

Ang, Andrew, Jean Boivin, et al. (2011). "Monetary Policy Shifts and the Term Structure". In: *The Review of Economic Studies* 78.2, pp. 429–457.

Ang, Andrew and Monika Piazzesi (2003). "A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables". In: *Journal of Monetary economics* 50.4, pp. 745–787.

Ang, Andrew, Monika Piazzesi, and Min Wei (2006). "What does the yield curve tell us about GDP growth?" In: *Journal of econometrics* 131.1-2, pp. 359–403.

Bauer and Rudebusch (2016). "Monetary Policy Expectations at the Zero Lower Bound". In: *Journal of Money, Credit and Banking* 48.7, pp. 1439–1465.

Bauer and Swanson (2023). "A Reassessment of Monetary Policy Surprises and High-Frequency Identification". In: *NBER Macroeconomics Annual* 37, pp. 87–155.

Beaudry, Paul and Franck Portier (2006). "Stock prices, news, and economic fluctuations". In: *American economic review* 96.4, pp. 1293–1307.

Bernard, Henri and Stefan Gerlach (1998). "Does the term structure predict recessions? The international evidence". In: *International Journal of Finance & Economics* 3.3, pp. 195–215.

BIS, MD (2005). "Zero-coupon yield curves estimated by central banks". In: *BIS papers* 25.

Brousseau, Vincent (2002). *The functional form of yield curves.* Working Paper Series 148. European Central Bank.

Campbell, John Y. and Robert J. Shiller (May 1991). "Yield Spreads and Interest Rate Movements: A Bird's Eye View". In: *The Review of Economic Studies* 58.3, pp. 495–514. ISSN: 0034-6527.

Carboni, Andrea and Alessandro Carboni (2010). "The Euro Area Yield Curve: An Analysis with Nelson-Siegel Type Models (February 1, 2010)". In: *SSRN Electronic Journal*. Available at SSRN: `https://ssrn.com/abstract=1962845` or doi:10.2139/ssrn.1962845.

Carriero, Andrea (2011). "FORECASTING THE YIELD CURVE USING PRIORS FROM NO-ARBITRAGE AFFINE TERM STRUCTURE MODELS". In: *International Economic Review* 52.2, pp. 425–459.

Carriero, Andrea, Todd E. Clark, and Massimiliano Marcellino (2021). "No-arbitrage priors, drifting volatilities, and the term structure of interest rates". In: *Journal of Applied Econometrics* 36.5, pp. 495–516.

Carriero, Andrea, George Kapetanios, and Massimiliano Marcellino (2012). "Forecasting government bond yields with large Bayesian vector autoregressions". In: *Journal of Banking & Finance* 36.7, pp. 2026–2047. ISSN: 0378-4266.

Chinn, Menzie and Kavan Kucko (2015). "The Predictive Power of the Yield Curve Across Countries and Time". In: *International Finance* 18.2, pp. 129–156.

Christiano, Lawrence J. (2012). "Christopher A. Sims and Vector Autoregressions". In: *The Scandinavian Journal of Economics* 114.4, pp. 1082–1104.

Coroneo, Laura, Ken Nyholm, and Rositsa Vidova-Koleva (2011). "How arbitrage-free is the Nelson–Siegel model?" In: *Journal of Empirical Finance* 18.3, pp. 393–407. ISSN: 0927-5398.

Culbertson, J. M. (Aug. 1957). "The Term Structure of Interest Rates". In: *The Quarterly Journal of Economics* 71.4, pp. 485–517. ISSN: 0033-5533.

Dewachter, Hans and Marco Lyrio (2006). "Macro Factors and the Term Structure of Interest Rates". In: *Journal of Money, Credit and Banking* 38.1, pp. 119–140. ISSN: 00222879, 15384616. (Visited on 09/17/2024).

Diebold and Li (2006). "Forecasting the term structure of government bond yields". In: *Journal of Econometrics* 130.2, pp. 337–364. ISSN: 0304-4076.

Diebold and Rudebusch (2013). *Yield curve modeling and forecasting: the dynamic Nelson-Siegel approach*. Princeton University Press.

Diebold, Rudebusch, and Aruoba (2006). "The macroeconomy and the yield curve: a dynamic latent factor approach". In: *Journal of econometrics* 131.1-2, pp. 309–338.

Dotsey, Michael (1998). "The predictive content of the interest rate term spread for future economic growth". In: *FRB Richmond Economic Quarterly* 84.3, pp. 31–51.

Duarte, Agustín, Ioannis A Venetis, and Ivan Paya (2005). "Predicting real growth and the probability of recession in the Euro area using the yield spread". In: *International Journal of Forecasting* 21.2, pp. 261–277.

Estrella, Arturo and Gikas A Hardouvelis (1991). "The term structure as a predictor of real economic activity". In: *The Journal of Finance* 46.2, pp. 555–576.

Estrella, Arturo and Frederic S Mishkin (1995). *The term structure of interest rates and its role in monetary policy for the European Central Bank*. Tech. rep. National Bureau of Economic Research.

— (1996). "The yield curve as a predictor of US recessions". In: *Current Issues in Economics and Finance* 2.7.

— (1998). "Predicting US recessions: Financial variables as leading indicators". In: *Review of Economics and Statistics* 80.1, pp. 45–61.

Estrella, Arturo and Mary Trubin (2006). "The yield curve as a leading indicator: Some practical issues". In: *Current Issues in Economics and Finance* 12.5.

Evans, Charles L and David A Marshall (1998). "Monetary policy and the term structure of nominal interest rates: evidence and theory". In: *Carnegie-Rochester Conference Series on Public Policy*. Vol. 49. Elsevier, pp. 53–111.

— (2007). "Economic determinants of the nominal treasury yield curve". In: *Journal of Monetary Economics* 54.7, pp. 1986–2003.

Evgenidis, Anastasios, Stephanos Papadamou, and Costas Siriopoulos (2018). "The yield spread's ability to forecast economic activity: What have we learned after 30 years of studies?" In: *Journal of Business Research*.

Fama, Eugene F and Robert R Bliss (1987). "The information in long-maturity forward rates". In: *The American Economic Review*, pp. 680–692.

Fama, Eugene F and Kenneth R French (1992). "The cross-section of expected stock returns". In: *the Journal of Finance* 47.2, pp. 427–465.

— (1993). "Common risk factors in the returns on stocks and bonds". In: *Journal of financial economics* 33.1, pp. 3–56.

Favara, Giovanni et al. (Oct. 2016). "Updating the Recession Risk and the Excess Bond Premium". In: *FEDS Notes*.

Fischer, Manfred M. et al. (2023). "General Bayesian time-varying parameter vector autoregressions for modeling government bond yields". In: *Journal of Applied Econometrics* 38.1, pp. 69–87.

Fisher, Irving (1930). "The Theory of Interest". In: *New York* 43, pp. 1–19.

Furlanetto, Francesco, Francesco Ravazzolo, and Samad Sarferaz (Nov. 2017). "Identification of Financial Factors in Economic Fluctuations". In: *The Economic Journal* 129.617, pp. 311–337. ISSN: 0013-0133.

Galí, Jordi (1992). "How Well Does the IS-LM Model Fit Postwar U.S. Data?" In: *The Quarterly Journal of Economics* 107.2, pp. 709–738. (Visited on 05/25/2024).

Gilchrist, Simon and Benoit Mojon (2014). *Credit Risk in the Euro area*. Working papers. Banque de France.

Gilchrist, Simon and Egon Zakrajšek (June 2012). "Credit Spreads and Business Cycle Fluctuations". In: *American Economic Review* 102.4, pp. 1692–1720.

Gomez-Cram, Roberto and Amir Yaron (May 2020). "How Important Are Inflation Expectations for the Nominal Yield Curve?" In: *The Review of Financial Studies* 34.2, pp. 985–1045. ISSN: 0893-9454.

Gürkaynak, Sack, and Swanson (May 2005). "Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements". In: *International Journal of Central Banking* 1.1.

Gürkaynak and Wright (June 2012). "Macroeconomics and the Term Structure". In: *Journal of Economic Literature* 50.2, pp. 331–67.

Hamilton, James D and Dong Heon Kim (2000). *A Re-examination of the Predictability of Economic Activity Using the Yield Spread*. Working Paper 7954. National Bureau of Economic Research.

Hamilton and Wu (2012). "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment". In: *Journal of Money, Credit and Banking* 44.s1, pp. 3–46.

Harvey, Campbell R. (1988). "The real term structure and consumption growth". In: *Journal of Financial Economics* 22.2, pp. 305–333.

Haubrich, Joseph G. (2006). "Does the yield curve signal recession?" In: *Federal Reserve Bank of Cleveland, Economic Commentary* Apr.

Hicks, John R. (1946). *Value and Capital, 2nd Edition.* Clarendon Press, Oxford.

Hördahl, Peter, Oreste Tristani, and David Vestin (2006). "A joint econometric model of macroeconomic and term-structure dynamics". In: *Journal of Econometrics* 131.1-2, pp. 405–444.

Jarociński, Marek and Peter Karadi (2020). "Deconstructing monetary policy surprises—the role of information shocks". In: *American Economic Journal: Macroeconomics* 12.2, pp. 1–43.

Kanjilal, Kakali (2011). "Macroeconomic factors and yield curve for the emerging Indian economy". In: *Macroeconomics and Finance in Emerging Market Economies* 4.1, pp. 57–83.

Kessel, Reuben A (1971). "The cyclical behavior of the term structure of interest rates". In: *Essays on Interest Rates, Volume 2.* NBER, pp. 337–390.

Kilian, Lutz and Helmut Lütkepohl (2017). *Structural Vector Autoregressive Analysis.* Themes in Modern Econometrics. Cambridge University Press.

Kilian, Lutz and Cheolbeom Park (2009). "The impact of oil price shocks on the US stock market". In: *International economic review* 50.4, pp. 1267–1287.

Krippner, Leo (Mar. 2012). *Modifying Gaussian term structure models when interest rates are near the zero lower bound.* Reserve Bank of New Zealand Discussion Paper Series DP2012/02. Reserve Bank of New Zealand.

— (2013). "Measuring the stance of monetary policy in zero lower bound environments". In: *Economics Letters* 118.1, pp. 135–138. ISSN: 0165-1765.

Kučera, Adam (2020). "Identification of triggers of US yield curve movements". In: *The North American Journal of Economics and Finance* 54, p. 101288.

Liu and Wu (2021). "Reconstructing the yield curve". In: *Journal of Financial Economics* 142.3, pp. 1395–1425.

Maes, Konstantijn (2002). "Macro factors and the term structure of interest rates". In: *Journal Of Money Credit And Banking* 38.1.

Martins, Manuel MF and António Afonso (2010). *Level, slope, curvature of the sovereign yield curve, and fiscal behaviour.* Tech. rep.

Mishkin, Frederic S (2015). *The Economics of Money, Banking and Financial Markets, 11th edition, Global Edition.* Pearson Education.

Moench, Emanuel (2008). "Forecasting the yield curve in a data-rich environment: A no-arbitrage factor-augmented VAR approach". In: *Journal of Econometrics* 146.1, pp. 26–43.

Moneta, Fabio (2005). "Does the yield spread predict recessions in the euro area?" In: *International Finance* 8.2, pp. 263–301.

Morales, Marco (2010). "The real yield curve and macroeconomic factors in the Chilean economy". In: *Applied Economics* 42.27, pp. 3533–3545.

Nakamura, Emi and Jón Steinsson (Jan. 2018). "High-Frequency Identification of Monetary Non-Neutrality: The Information Effect*". In: *The Quarterly Journal of Economics* 133.3, pp. 1283–1330. ISSN: 0033-5533.

Nakamura, Nao Sudo, and Yu Sugisaki (2024). “Assessing monetary policy surprises in Japan by high frequency identification”. In: *Journal of the Japanese and International Economies* 71, p. 101300. ISSN: 0889-1583.

Nelson, Charles R and Andrew F Siegel (1987). “Parsimonious modeling of yield curves”. In: *Journal of business*, pp. 473–489.

Nyberg, Henri (2010). “Dynamic probit models and financial variables in recession forecasting”. In: *Journal of Forecasting* 29.1-2, pp. 215–230.

Nyholm, Ken (2015). *A Rotated Dynamic Nelson-Siegel Model with Macro-Financial Applications*. ECB Working Paper No. 1851. Available at SSRN: `https://ssrn.com/abstract=2666978` or doi:10.2139/ssrn.2666978. European Central Bank (ECB).

Nyholm, Ken and Rositsa Vidova-Koleva (2010). *Nelson-Siegel, Affine and Quadratic Yield Curve Specifications: Which One is Better at Forecasting?* ECB Working Paper No. 1205. Available at SSRN: `https://ssrn.com/abstract=1610230` or doi:10.2139/ssrn.1610230. European Central Bank (ECB).

Nymand-Andersen, Per (2018). *Yield curve modelling and a conceptual framework for estimating yield curves: evidence from the European Central Bank's yield curves.* 27. ECB Statistics Paper.

Ormos, Mihály and Miklós Vázsonyi (2011). “Impacts of public news on stock market prices: Evidence from S&P500”. In: *Interdisciplinary Journal of Research in Business* 1.2, pp. 1–17.

Pearce, Douglas K and V Vance Roley (1984). *Stock prices and economic news.* Tech. rep. National bureau of economic research.

Pedersen, Hal and Swanson (2019). “A survey of dynamic Nelson-Siegel models, diffusion indexes, and big data methods for predicting interest rates”. In: *Quantatitive Finance and Economics* 3, pp. 22–45.

Perold, André F (2004). “The capital asset pricing model”. In: *Journal of economic perspectives* 18.3, pp. 3–24.

Rosenberg, Joshua V and Samuel Maurer (2008). “Signal or noise? Implications of the term premium for recession forecasting”. In: *Federal Reserve Bank of New York, Economic Policy Review* 14.1.

Rudebusch, Glenn D (1998). “Do measures of monetary policy in a VAR make sense?” In: *International economic review*, pp. 907–931.

— (2005). “Monetary policy inertia: fact or fiction?” In: *FRB of San Francisco Working Paper* 2005-19.

Rudebusch, Glenn D and John C Williams (2009). “Forecasting recessions: the puzzle of the enduring power of the yield curve”. In: *Journal of Business & Economic Statistics* 27.4, pp. 492–503.

Rudebusch and Wu (2008). “A macro-finance model of the term structure, monetary policy and the economy”. In: *The Economic Journal* 118.530, pp. 906–926.

Schock, Matthias (2014). *Do eurozone yield spreads predict recessions?* Diskussionsbeitrag 532. Hannover: Discussion Paper, Wirtschaftswissenschaftliche Fakultät, Leibniz University.

Sims, Christopher A (1980). "Macroeconomics and reality". In: *Econometrica: journal of the Econometric Society*, pp. 1–48.

Söderlind, Paul and Lars Svensson (1997). "New techniques to extract market expectations from financial instruments". In: *Journal of Monetary Economics* 40.2, pp. 383–429.

Stock, James and Mark Watson (1989). "New indexes of coincident and leading economic indicators". In: *NBER macroeconomics annual* 4, pp. 351–394.

— (2001). "Vector autoregressions". In: *Journal of Economic perspectives* 15.4, pp. 101–115.

— (2003). "How did leading indicator forecasts perform during the 2001 recession?" In: *FRB Richmond Economic Quarterly* 89.3, pp. 71–90.

Svensson, Lars EO (1994). *Estimating and interpreting forward interest rates: Sweden 1992-1994.*

Swanson (2021). "Measuring the effects of federal reserve forward guidance and asset purchases on financial markets". In: *Journal of Monetary Economics* 118, pp. 32–53. ISSN: 0304-3932.

Taylor, John B (1993). "Discretion versus policy rules in practice". In: *Carnegie-Rochester conference series on public policy.* Vol. 39. Elsevier, pp. 195–214.

Wheelock, David C, Mark E Wohar, et al. (2009). "Can the term spread predict output growth and recessions? A survey of the literature". In: *Federal Reserve Bank of St. Louis Review* 91.5 Part 1, pp. 419–440.

Wright (2006). "The yield curve and predicting recessions". In: *Finance and Economics Discussion Series, Board of Governors of the Federal Reserve System (US)* 2006–7.

— (2012). "What does Monetary Policy do to Long-term Interest Rates at the Zero Lower Bound?" In: *The Economic Journal* 122.564, F447–F466.

Wu, Tao (2001). "Monetary policy and the slope factor in empirical term structure estimations". In: *FRB of San Francisco Working Papers* 2002-07.

Wu and Xia (2016). "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound". In: *Journal of Money, Credit and Banking* 48.2-3, pp. 253–291.

A Appendix

Data US

- Industrial Production (FRED: INDPRO)
- CPI (FRED: CPIAUCSL)
- Federal Funds Effective Rate (FRED: DFF)
- S&P 500 (Yahho Finance: ˆGSPC)
- Excess Bond Premium (EBP)[12]
- β factors based on yields data provided by Liu and Wu (2021)[13]

Data EA

- Industrial Production (FRED: EA19PRINTO01GYSAM)
- Inflation (FRED: CPHPTT01EZM659N)
- 3M Interbank Rate (FRED: IR3TIB01EZM156N)
- Eurostoxx 50 (Yahho Finance: ˆSTOXX50E)
- Credit Risk EA[14]
- β factors based on yields data provided by the ECB[15]

[12] source: Fed Note Data

[13] source: Liu-Wu Yield Data

[14] source: Banque de France

[15] source: dataset "All years - AAA"

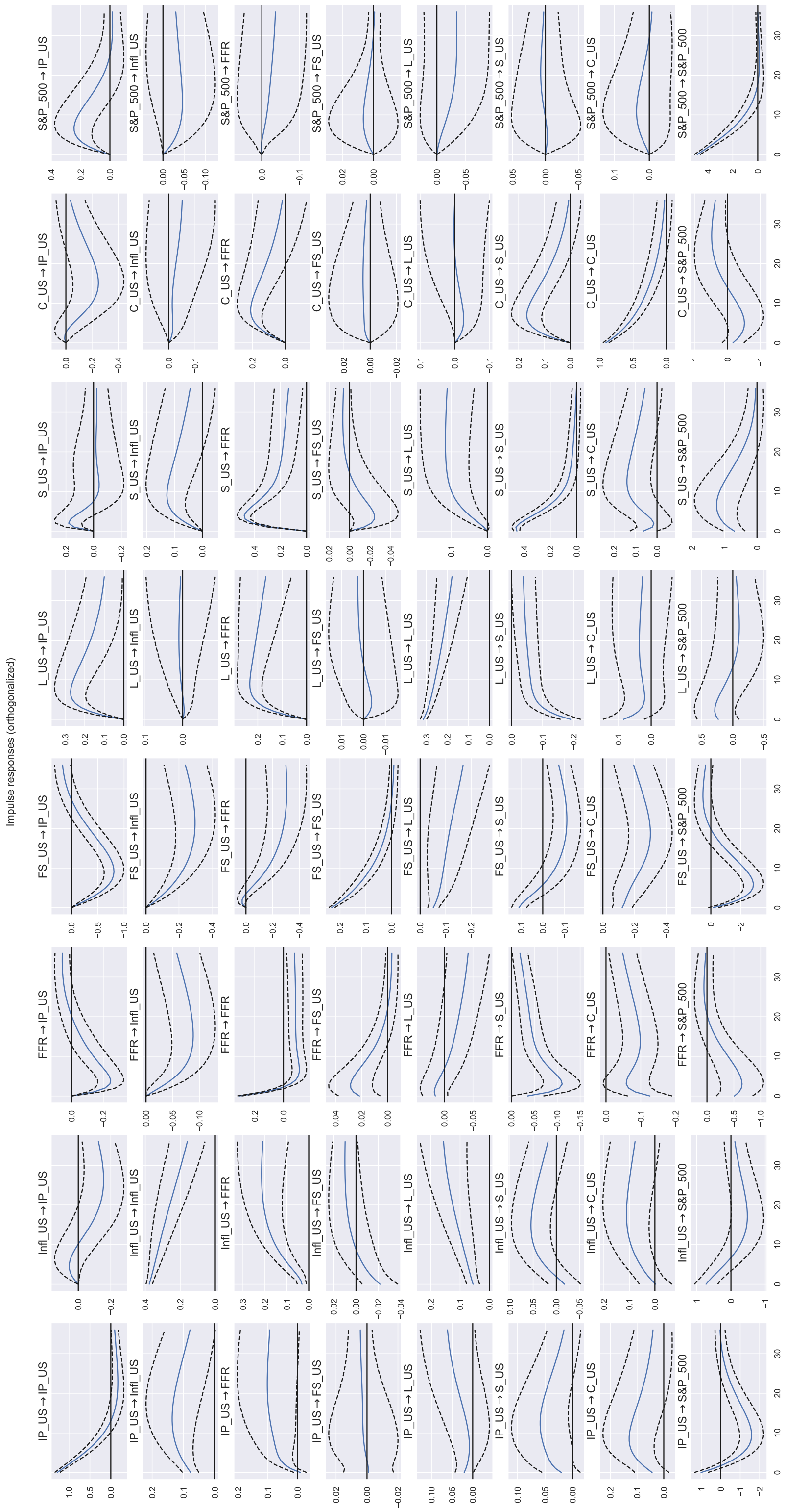

Figure 13: Impulse Responses SVAR(1), US

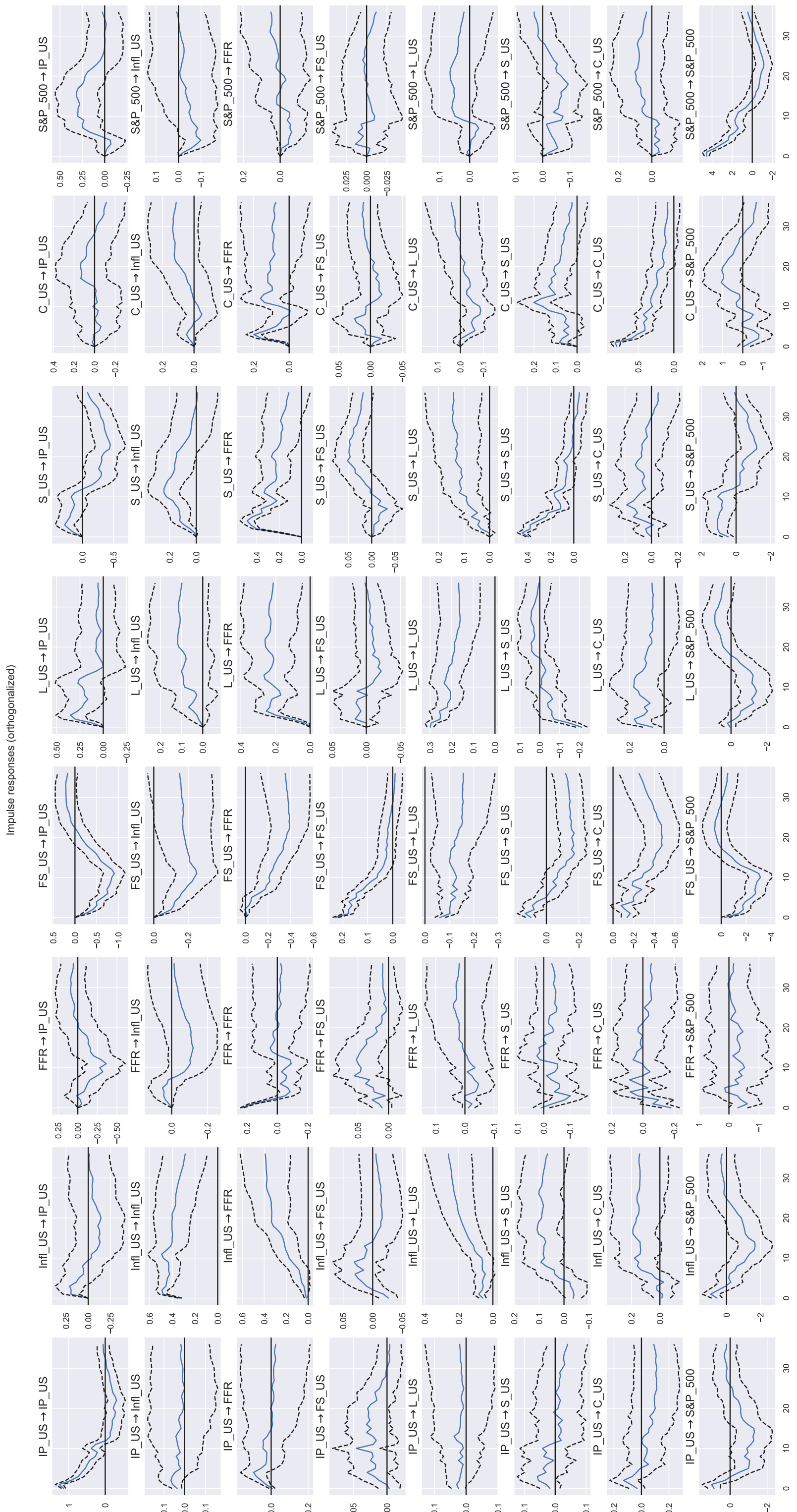

Figure 14: Impulse Responses SVAR(12), US

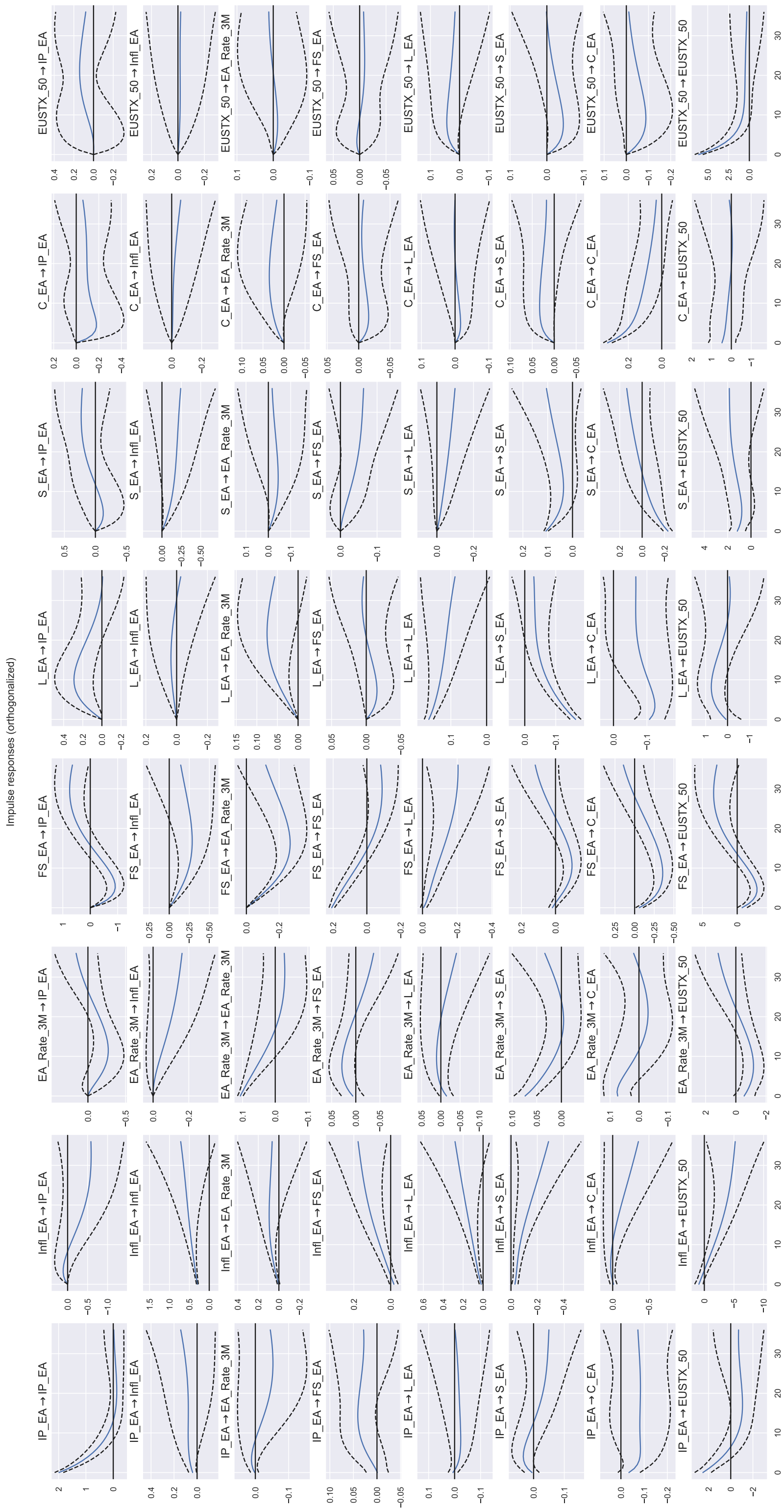

Figure 15: Impulse Responses SVAR(1), EA

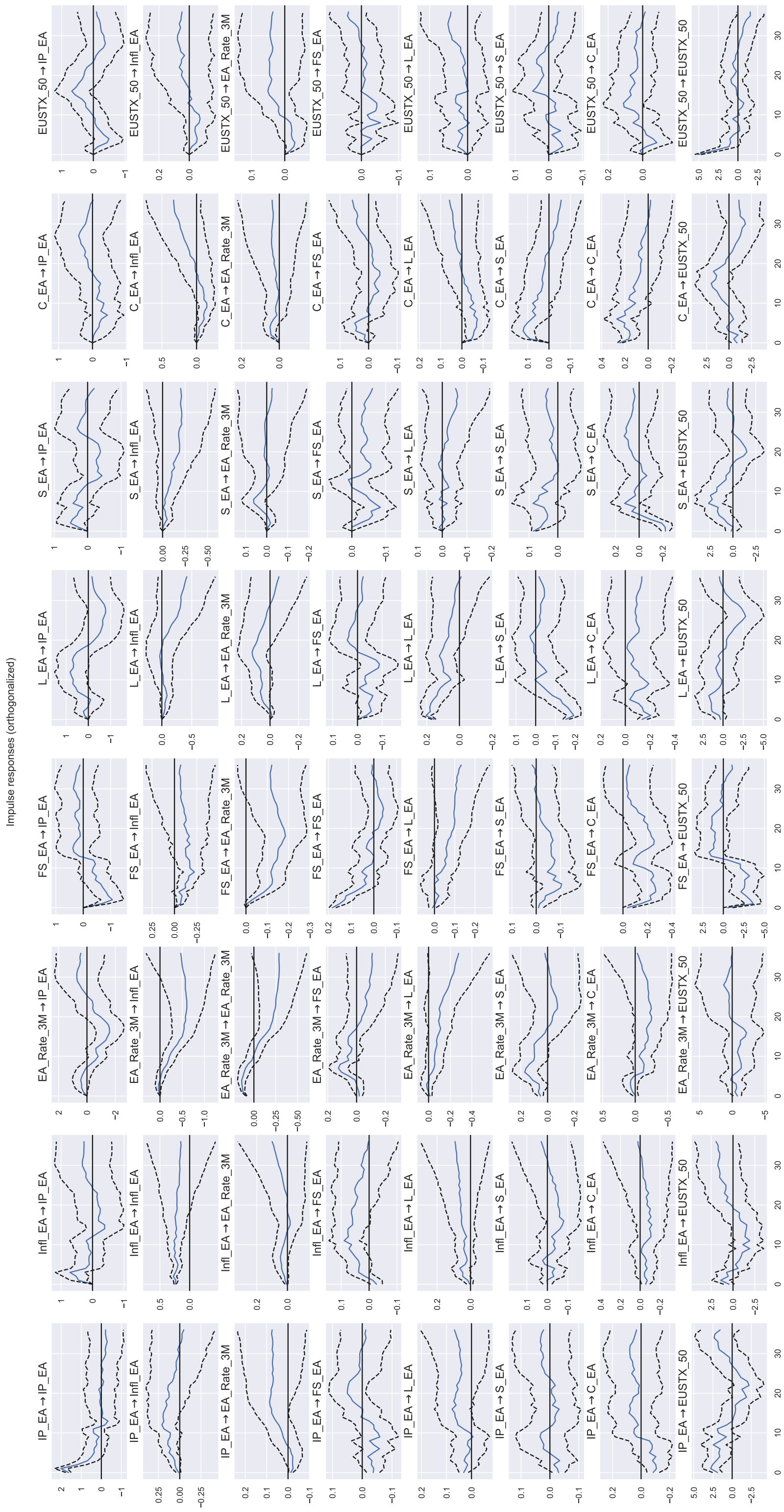

Figure 16: Impulse Responses SVAR(12), EA

	t-Statistic	Critical value	p-value
IP_t^{US}	-4.4167	-2.8668	0.0003
π_t^{US}	-2.6651	-2.8668	0.0803
i_t^{US}	-2.3033	-2.8669	0.1709
FS_t^{US}	-4.0171	-2.8669	0.0013
L_t^{US}	-1.1053	-2.8667	0.7129
S_t^{US}	-4.2243	-2.8669	0.0006
C_t^{US}	-2.7331	-2.8668	0.0685
M_t^{US}	-4.5309	-2.8668	0.0002

Table 5: Augmented Dickey-Fuller (ADF) unit root test, US

	t-Statistic	Critical value	p-value
IP_t^{EA}	-3.0298	-2.8760	0.0322
π_t^{EA}	-0.8543	-2.8760	0.8027
i_t^{EA}	-1.5388	-2.8761	0.5143
FS_t^{EA}	-3.1743	-2.8751	0.0215
L_t^{EA}	-1.3095	-2.8751	0.6248
S_t^{EA}	-2.2388	-2.8753	0.1925
C_t^{EA}	-1.7449	-2.8758	0.4082
M_t^{EA}	-2.9763	-2.8759	0.0372

Table 6: Augmented Dickey-Fuller (ADF) unit root test, EA