Macroeconomic fundamentals and latent factor of the EU yield curve

Marius Acatrinei[63]

The content of this study does not reflect the official opinion of EIOPA. Responsibility for the information and the views expressed therein lies entirely with the authors.

Abstract

Since the portfolio of the insurers consists largely of bonds, out of which a significant weight consists of Government bonds, insurers are mainly exposed to interest rate risk and sovereign risk. We are motivated to contribute to the debate around the effect of the low yield environment and the effect on the insurers' portfolio due to their high exposure to government bonds. In this respect, any rise in macroeconomic risk across Europe could lead to a joint hit to insurers. The paper provides a broader look of the impact of the macroeconomic variables on the underlying factors that describe the yield curve and their overall effects to the insurers' portfolio. We show that the macroeconomic shocks have a different impact on bonds depending on their maturity. The life insurers are more affected by the low interest rate because the duration of long-term liabilities rises more than the one of the short-term assets. Therefore, the sensitivity of the long-term bonds to interest rate change is important for life insurers. We have estimated a structural VECM model to explore the interaction between the macroeconomic variables and the estimated factors of the yield curve. We conclude that 1) any change in the actual inflation can lead to small increases in the level factor, leaving almost unchanged the bond prices 2) the slope factor decreases faster after the monetary policy shocks affecting mostly the short-term bonds 3) a positive shock in monetary policy rate leads to a strong increase of the level factor.

Keywords: insurance, yield curve, Dynamic Factor Model, structural VECM.

JEL Codes: G22, C32, D53

Introduction

Holding assets that account for about two-thirds of European GDP, the European insurance sector is a significant part of the financial sector and one of the largest institutional investors. Insurers provide protection against financial and economic risks and an important source of long-term funding since they have a long-term strategy. They act mostly as shock absorbers in financial markets, but some latest developments show that they become more interconnected with the financial markets. In the case of liquidity swaps, the banks have access to the liquidity of insurers' asset portfolios. The banks borrow highly liquid government bonds and provide illiquid assets as collateral. Thus the vulnerability of insurers to financial system impairment is increased and passed through in the financial markets as liquidity risk.

The EIOPA Insurance stress test (2016) highlighted that prolonged low interest rate environment, combined with other factors could have a substantial negative impact on many European insurers reflected by a decrease in total excess of assets over

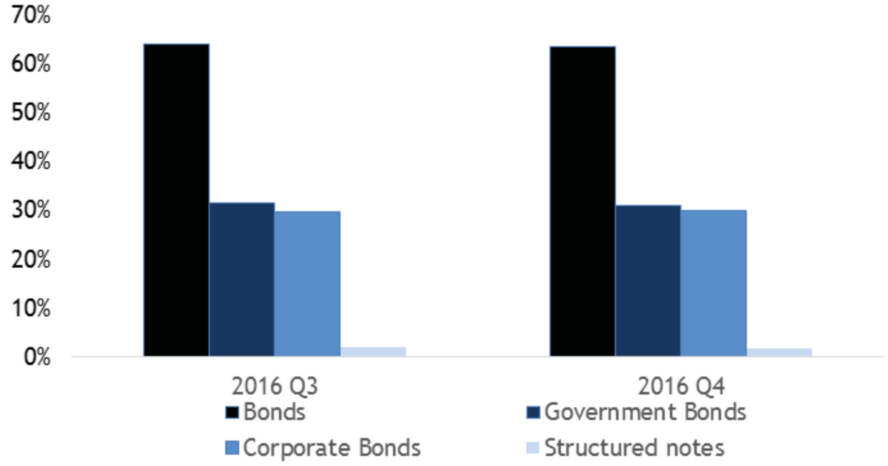
[63] Senior Economist at Financial Supervisory Authority (Romania) and Associate Researcher at Institute for Economic Forecasting. Email: marius.acatrinei@gmail.com.

liabilities. In this scenario[64], the impact of macroeconomic variables gains more importance on the insurers' profitability and solvency. Low interest rates coupled with a low growth environment characterized by declining asset prices can have significant financial stability implications. Expectations of a low-for-long scenario could lead insurers to invest in riskier, illiquid assets, thus increasing their probability of defaults.

According to the Solvency II balance sheet data[65], the weight of the bonds in the investments insurers' portfolio was around 63% in Q4 2016, out of which 31% were government Bonds (Figure A.1).

As a significant weight consists of bonds and government bonds, the insurers are mainly exposed to interest rate risk and sovereign risk. The insurers have a greater exposure to market risk through asset and liability duration mismatches, given the increased sensitivity of their investment portfolio to interest rates. The risk increase is mainly due to the high commonality in exposures to aggregate risk and thus they are nowadays more likely to be affected by any difficulties of the financial system.

Figure A.1: Weight of bonds in the European insurers' balance sheets



Source: EIOPA, Balance Sheet data

The academic research on the term structure of the interest rates showed that the yield curve can be described by a few statistical factors. While the Diebold et al (2006) paper analyses both the impact of the macroeconomic factors on the yield curve and vice versa, we are more interested to understand the shock of macroeconomic variables on the European yield curve. In this respect we have estimated a dynamic factor model which includes three observable macroeconomic factors: inflation, monetary policy rates and industry capacity utilizations along the yields of European government bonds. Since the factors that shape the structure of the yield curve have an important effect on the European economic climate, we study the impact of economic variables through an Impulse Response function.

After the global financial crisis of 2007-2009, the macroeconomic models were criticized for failing to property capture the negative consequences of macrofinancial interlinkages between the financial sector and the macroeconomy.

[64] It has to be considered that there were some deviations from the SII regulation, e.g. in the so called "low-for-long" scenario the UFR was decreased to 2%. There was also no recalculation of the capital requirements after stress in the hypothetical scenarios.

[65] See EIOPA Statistics, Solo/Quarterly/Published 20170918 / Data extracted 20170829 (1) and FS/Annual/Published 20170918 / Data extracted 20170828.

Ang and Piazzesi (2003), Hordahl (2008) and Rudebusch and Wu (2008) developed models on the yield curve which included macroeconomic variables. Hordahl (2008) showed that although a hawkish monetary policy rule reduces the inflation risk premia embodied in the term structure of interest rates, it doesn't necessarily flatten the yield curve.

The models which explore the relationship between yield curve and macroeconomic variables are dynamic and are cast in the framework of Nelson and Siegel (1987) by extracting three latent factors from the yield. The Nelson-Siegel framework is used in practice by Central Banks, investment banks etc. for estimating the yield curve of the treasury bonds.

There are different narratives on how the macroeconomic factors influence the yield curve. Ang and Piazzesi (2003) showed that inflation and economic activity explain the dynamics of short and medium-term yield curves. Rudebusch and Wu (2008), Afonso and Martins (2012) have included macroeconomic variables in order to analyze the monetary and fiscal shocks on the yield curve. In order to identify the shocks, the authors implemented a sign restriction scheme (Canova and de Nicolo 2002) and a block diagonal strategy as in Mumtaz and Surico (2009) because they assumed that the macro variables affect simultaneously the yield curve factors. The level and slope factors are negatively correlated. The level factor accounts for the parallel shift in the yield curve, while the second factor explains the steepness of the curve in the slope. Usually when the level factor increases, the slope factor decreases.

Following this line of reasoning, the volatility of the term structure was analyzed by using the second factor of the yield curve. The motivation was that the second factor can provide information of the uncertainty of the future interest rate.

There is a rich literature on economic factors affecting the yield curve factors. Hardle (2012) used five macroeconomic variables: the harmonized consumer price index, the manufacturing capacity utilization, the unemployment rate, industrial production and the real Gross Domestic Product. The results show that the first factor is mainly driven by three factors: the inflation rate, the real Gross Domestic Product and the industrial production. It should be noted that the macroeconomic fundamentals could not explain the dynamics for the second factor.

The focus of the macroprudential policies is to bring light on the factors that may pose significant threats to the economy. Our paper may provide a broader look of the impact of the macroeconomic variables on the latent factors on the macroeconomic developments and as a basis for macrofinancial stress testing.

Data

We have used the yields of European Government bonds with maturities of 3, 6, 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 months. The data was provided by Datastream Thompson. The yields were not transformed in zero coupon yields because the differences were very small.

As the industry capacity utilisation is quarterly data and seasonally adjusted, we have disaggregated the series in monthly data using the Industrial Production Index with a small state space model as in Matteo Pelagatti (2015). The industrial production index is published monthly with a lag of one month and is available on Eurostat. The Harmonised Consumer Price Index (HICP) (2010=100) is published monthly with a lag of one month and is available on Eurostat. The monetary policy rate (Euro Short Term Repo Rate) is available on the website of the European Central Bank.

Following Diebold et al (2006) methodology, three underlying factors (level, slope and curvature) were extracted from the European government yields during 2008-2017. These factors can explain most of the variation of the yield curve. The level factor can be linked to inflation expectations, while the slope factor is related with the business cycle and with the uncertainty of the future interest rate.

Model

Nelson-Siegel equations for fitting the curve yield

According to Nelson-Siegel (1987) the instantaneous forward interest rate is the solution to a second order differential equation. The Nelson-Siegel equation for the yield curve is

$$y(x) = L + S\left(\frac{1-e^{-\lambda x}}{\lambda x}\right) + C\left(\frac{1-e^{-\lambda x}}{\lambda x} - e^{-\lambda x}\right)$$

The latent factors extracted from the yield curve (y) are known in the literature as Level (L), Slope (S) and Curvature (C).

A dynamic factor model allows the analysis of the extracted factors as they are transposed in a state space model

$$y(x) = L + S\left(\frac{1-e^{-\lambda x}}{\lambda x}\right) + C\left(\frac{1-e^{-\lambda x}}{\lambda x} - e^{-\lambda x}\right)$$

Diebold and Li (2002) showed that the factors L, S and C are time dependent in a dynamic model and therefore can be modeled as

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

Interpretation of the latent factors

We did not extract the factors with a PCA model (principal component analysis) as a PCA model considers the factors as orthogonal (uncorrelated). In a state space model with full diagonal specification for the state error covariance matrix, we can see how they influence each other.

The first factor is the level factor as any change in it leads to parallel shifts in the term structure of interest rate, meaning that it brings a shifting of the interest rate for any maturity. The level factor usually explains around 80% of the total variation of the yield curve. By construction the loading of the level factor does not change with maturity and thus affects all yields by the same amount.

The second factor is the slope as any change in it brings an asymmetric response on the short and long-term maturities. A shock to the slope means that the short-term bonds increase faster than the long-term ones. It explains around 15% of the yield curve. The loading of the slope factor equals one at zero maturity and declines to zero as the maturity increases.

The third factor is called curvature as the shocks to it leads to changes in the middle of the yield curve. It explains around 5% of the yield curve. The monetary policy rate affects primarily the short-term interest rate. The long-end of the curve yield depends on the market expectations and risk aversion on future economic developments.

State-space representation of the dynamic factor model

We assume that the factors L_t, S_t, C_t are following a Vector autoregressive process of order 1 (VAR1). Since any ARMA process may be written in the state space framework (Hamilton, 1994), the equations are written as follows:

Transition equation

$$\boldsymbol{\alpha_{t+1}} = \boldsymbol{T\alpha_t} + \boldsymbol{\eta_t}, \boldsymbol{\eta_t} \sim (\boldsymbol{0}, \boldsymbol{Q})$$

The state vector of factors follows a first-order autoregressive process. We discard the mean from the state variables

$$\boldsymbol{\alpha_{t+1}} - \boldsymbol{\mu} = \boldsymbol{T}(\boldsymbol{\alpha_t} - \boldsymbol{\mu}) + \boldsymbol{\eta_t}$$

$$\begin{bmatrix} L_{t+1} - \mu_L \\ S_{t+1} - \mu_S \\ C_{t+1} - \mu_C \end{bmatrix} = \begin{bmatrix} a_{11} a_{12} a_{13} \\ a_{21} a_{22} a_{23} \\ a_{31} a_{32} a_{33} \end{bmatrix} \begin{bmatrix} L_{t+1} - \mu_L \\ S_{t+1} - \mu_S \\ C_{t+1} - \mu_C \end{bmatrix} + \begin{bmatrix} \eta_t(L) \\ \eta_t(S) \\ \eta_t(C) \end{bmatrix}$$

We don't assume that the Q matrix is diagonal which means that the shocks of the state variables influence each other.

The column vector of yields of the European government bonds is y_t

Measurement equation

$$\boldsymbol{y_t} = \boldsymbol{Z\alpha_t} + \boldsymbol{\varepsilon_t}, \boldsymbol{\varepsilon_t} \sim (\boldsymbol{0}, \boldsymbol{H_t})$$

$$\begin{pmatrix} y_{1,t} \\ \vdots \\ y_{N,t} \end{pmatrix} = \begin{pmatrix} 1 & \dfrac{1 - e^{-\lambda x_1}}{\lambda x_1} & \dfrac{1 - e^{-\lambda x_1}}{\lambda x_1} - e^{-\lambda x_1} \\ \vdots & \vdots & \vdots \\ 1 & \dfrac{1 - e^{-\lambda x_N}}{\lambda x_N} & \dfrac{1 - e^{-\lambda x_N}}{\lambda x_N} - e^{-\lambda x_N} \end{pmatrix} \begin{pmatrix} L_t \\ S_t \\ C_t \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \vdots \\ \varepsilon_{N,t} \end{pmatrix}$$

where λ is a parameter which controls the strength of the relationship between the latent factors and the observed yields, that is the speed of exponential decay with smaller values associated with slow decay rates. The measurement errors (ε_t) allows for movements in the yields that are not explained by the state variables.

We assume that the measurement errors and the state errors are orthogonal such as

$$\begin{pmatrix} \eta_t \\ \varepsilon_t \end{pmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} Q & 0 \\ 0 & H \end{pmatrix} \right]$$

Empirical Results

Following Diebold et al. (2006) we have estimated a dynamic factor model with a full diagonal specification for the state error covariance matrix in order to inspect the influence between factors.

In order to assess the influence of macroeconomic variables on the yield curve, we have re-estimated the model by adding monetary policy rate, inflation and industry capacity utilization. The industry capacity utilization (CAP) is a proxy for the economic activity. Since the monetary policy rate (Repo) influences all the interest rates in the economy, it is usually used in all models in the literature surveyed. Inflation (HICP) is added to the model in order to see the causal relation between macroeconomic policy, real economy and bond yields.

We have estimated the model with the Kalman filter (smoother filter). The smoothed values will be presented in the graphs below in order to check the fit of the model. The likelihood test and the Wald test for the diagonality of Q matrix show that we can reject the null hypothesis that Q is a diagonal matrix and accept the alternative hypothesis that Q is not diagonal.

$$\begin{bmatrix} L_{t+1}-\mu_L \\ S_{t+1}-\mu_S \\ C_{t+1}-\mu_C \\ CAP_{t+1}-\mu_{CAP} \\ Repo_{t+1}-\mu_{repo} \\ HICP_{t+1}-\mu_{HICP} \end{bmatrix} = \begin{bmatrix} 0.91 & \mathbf{0.12} & \mathbf{-0.02} & -0.07 & \mathbf{-0.13} & 0.02 \\ 0.27 & 0.99 & \mathbf{0.03} & 0.06 & \mathbf{-0.02} & -0.1 \\ \mathbf{-0.1} & \mathbf{-0.13} & 0.91 & \mathbf{0.02} & 0.46 & -0.27 \\ 0.77 & 0.65 & 0.05 & 0.98 & -1.11 & 0.18 \\ 0.26 & 0.29 & 0.01 & -0.02 & 0.6 & 0.11 \\ \mathbf{0.12} & \mathbf{0.13} & \mathbf{0.03} & \mathbf{-0.004} & -0.23 & 1.06 \end{bmatrix}$$

$$\begin{bmatrix} L_t-\mu_L \\ S_t-\mu_S \\ C_t-\mu_C \\ CAP_t-\mu_{CAP} \\ Repo_t-\mu_{repo} \\ HICP_t-\mu_{HICP} \end{bmatrix} + \begin{bmatrix} 4.14 \\ -3.31 \\ -4.01 \\ 81.13 \\ 1.24 \\ 2.42 \end{bmatrix}$$

*bold: not significant values (pvalue > 0.05)

The results show a persistent dynamic for the first three factors with their previous lag respectively 0.91 for Lt, 0.99 for St and 0.91 for Ct. The dynamics between the latent factors is as follows: Lt is not influenced by St or Ct, St is influenced by Lt (0.27) and Ct is not influenced by the first two factors.

The relationship between the latent factors and the macroeconomic variables is: Lt is negatively influenced by capacity utilization and positively by inflation. On the contrary St is positively influenced by capacity utilization and negatively by inflation.

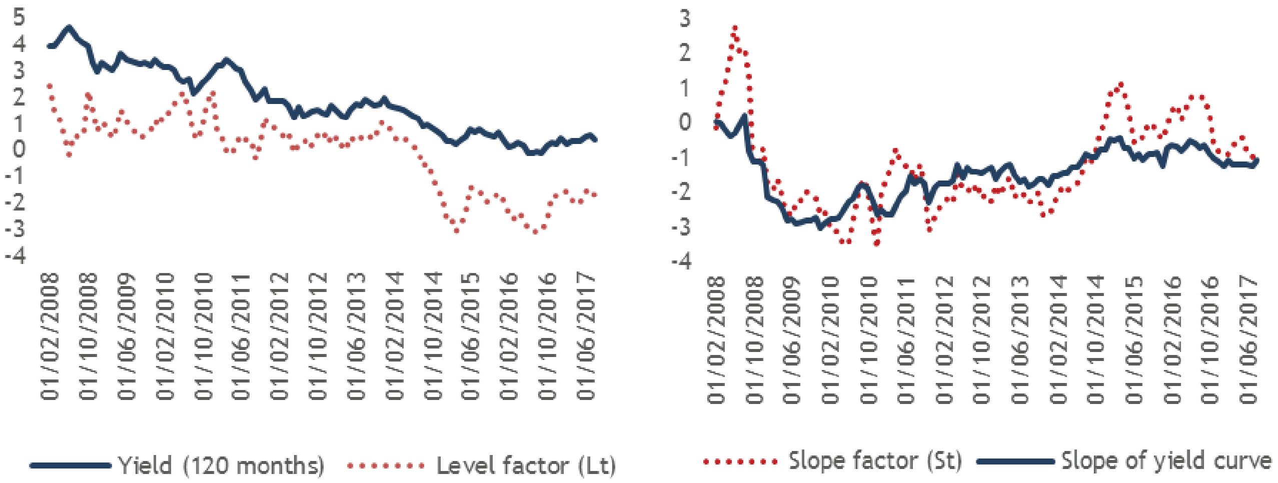
The correlation between the Hodrick-Prescott (HP) cycles between St and capacity utilization in industry is 0.175 and suggests that St is linked to the business cycle.

Table A.1. Estimated Q matrix (state error covariance matrix)

	L_t	S_t	C_t	CAP	Repo	HICP
L_t	**0.05** (0.0000)					
S_t		**0.09** (0.0000)				
C_t			**0.37** (0.0000)			
CAP				**0.17** (0.0000)		
Repo					**0.01** (0.0000)	
HICP						**0.07** (0.0000)

The transition shock volatility is lower for the first two factors while for the third factor is higher (0.37). We may note that the shock volatility for the first factor is quite low due to the very small changes in the Lt in the last years.

Figure A.2: Estimated factors versus their empirical proxies



Source: Author's own calculation

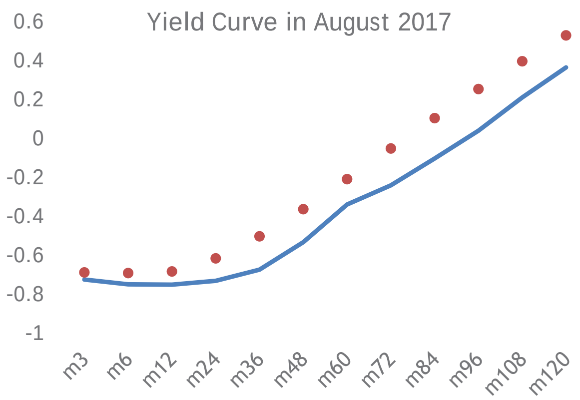
The empirical proxy for the level factor is the long-term yield of 10 years' bonds. The level factor is highly correlated with the long-term yields (120 months) and it can be interpreted as including inflation expectations.

The empirical proxy for the slope factor is the difference between short-term yield (3 months) and long-term yields (120 months). When the curve is negative it means that the yields tend to increase as the maturity increases and describes a normal economy while an inverted yield curve is described by a positive slope.

The results show that until the end of 2014 the decrease in the monetary policy rate coincided with a decrease in the slope factor, while after 2014 the slope began to increase.

We show that the fit of the model by plotting the actual versus fitted yield curve for August 2017. The estimation errors are very small and they tend to be slightly bigger for the long-term yields.

Figure A.3: Actual (blue line) and Fitted (red circles) yield curves



Source: Author's own calculation

Vector Error Correction Model

As both the latent factors (level factor, slope factor) and macroeconomic variables (monetary policy rate, inflation rate, industry capacity utilization,) are nonstationary variables, we have fitted a structural VECM model with two lags and two cointegrating relations in order to analyze the causal patterns between the macroeconomic variables and the factors that characterize the yield curve. We have imposed 10 short-term restrictions and a recursive identification scheme for the shocks. The variables were ordered from the most exogenous to the least exogenous (monetary policy rate, level factor, slope factor, inflation, and capacity utilization). The variables that are most exogenous affect contemporaneously variables as level factor and slope factor, while affecting other variables with a lag.

Table A.2: Estimated B matrix

	monetary policy	**L_t**	**S_t**	**HICP**	**CAP**
monetary policy	0.0445	-0.0584	**0**	**0**	**0**
L_t	0.2069	0.3137	**0**	**0**	**0**
S_t	-0.217	-0.342	0.1071	0.018	**0**
HICP	0.014	-0.0211	**0**	0.0929	-0.0132
CAP	**0**	-0.0134	**0**	0.0094	0.061

Source: Author's own calculation

We choose this ordering due to the fact that since our data are monthly, it takes time for economic agents to react to economic developments and policy decisions, while other variables react immediately.

Figure A.4: Cointegration graph

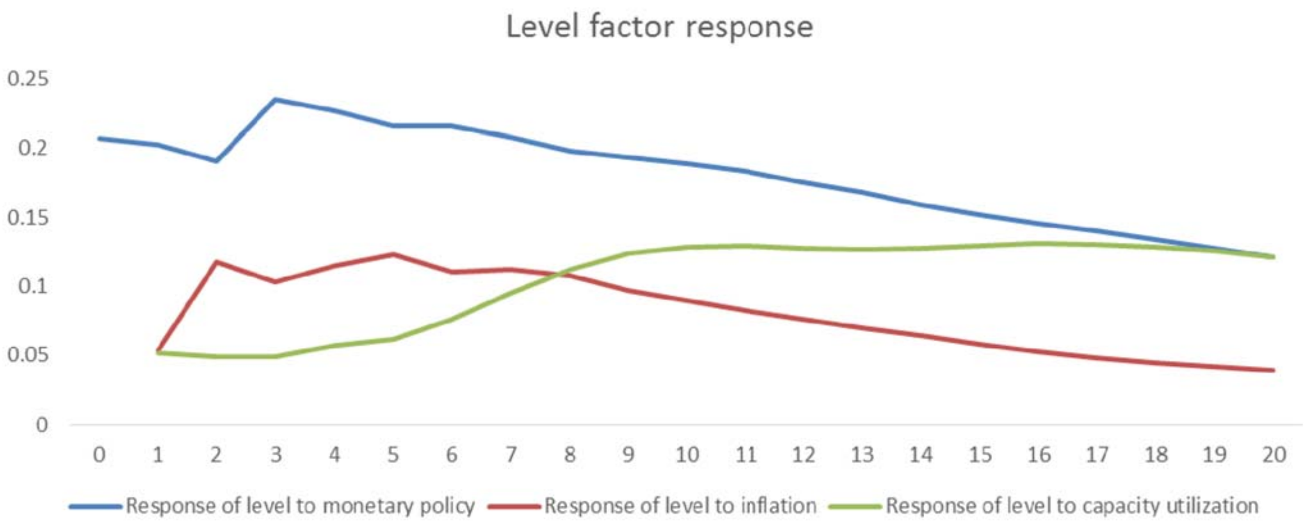
Source: Author's own calculation

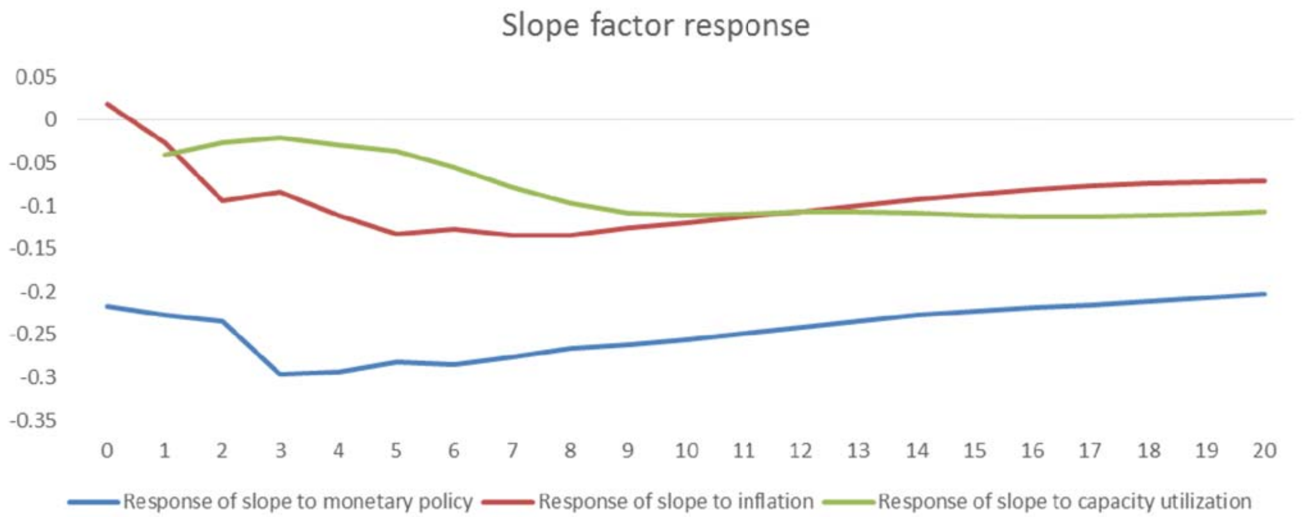
The cointegration plot shows that the deviations from equilibrium are very small since 2014.

Impulse-response analysis is typically used to describe the response in the variables chosen due to a shock in other variables. The impulse is defined as generalized impulse (Pesaran and Shin, 1998) so as not to depend on the variable ordering.

In the following we will present only the impulse-response from the macroeconomic variables to the latent factors. Since the model is VECM, most shocks don't die out.

Figure A.5: Impulse Response Functions





Source: Author's own calculation

Conclusions

We have used monthly data between January 2008 and August 2017 for 12 European Government yields with maturities ranging from 3 to 120 months, inflation rate excluding energy and food (HICP), industry capacity utilization and the ECB monetary policy rate. Then we have estimated a structural VECM model to analyze the interaction between the first two statistical factors (level and slope) and the three selected macroeconomic variables, the ECB monetary policy rate, industry capacity utilization and inflation rate.

The results showed that the increases in the level factor are usually associated with the inflation expectation. While the increases in the level do not have a contemporaneous increase of the slope factor, an increase in the slope factor has a negative contemporaneous effect on the level.

A positive shock in inflation (HIPC less energy and food) leads to an increase in level and decrease the slope. Rudebusch and Wu (2008) showed that movements in the inflation rate may explain around 66% of the level factor dynamics. In normal market conditions, the increase in inflation expectations leads to an increase of long-term yields in order to compensate the investors for the losses caused by inflation. In the low yield environment, the relationship between inflation and inflation expectations is marred by the low growth expectations for the long-run. Any change in the actual inflation can lead to small increases in inflation expectations, meaning that the bond prices will be almost unchanged.

The shocks to the economic activity affects the yield curve, through the demand channel since companies are issuing more long-term bonds. A modest increase in the growth of the European economy will have only a marginally decrease in the bond prices. A shock in the industry capacity utilization brings about a positive shock in the level factor and a positive shock in the level factor and a negative shock to the slope factor since the short-term loans are used to finance business operations.

A positive shock in the monetary policy rate (monetary policy tightening) leads to a decrease in the inflation expectations and to an increase in the level factor, but also to a decrease in the slope factor which measures the uncertainty around the future interest rate. The slope factor reacts contemporaneously to any news regarding the change of the monetary policy rate. After the official release, since the uncertainty is abated, the shock persists since is affected also by the level factor.

The slope factor decreases faster after any shock in the monetary policy, meaning the short-term bond prices are the most affected.

As the macroeconomic shocks have different effects on bonds given the term structure of insurers ‘portfolios, the effects of the macroeconomic variables on the insurers’ assets distribution depend on the weight and maturity of bonds held by insurers.

References

Afonso, A., & Martins, M. M. (2012). Level, slope, curvature of the sovereign yield curve, and fiscal behaviour. *Journal of Banking & Finance*, *36*(6), 1789-1807.

Ang, A., & Piazzesi, M. (2003). A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables. *Journal of Monetary economics*, *50*(4), 745-787.

Bianchi, F., Mumtaz, H., & Surico, P. (2009). The great moderation of the term structure of UK interest rates. *Journal of Monetary Economics*, *56*(6), 856-871.

Canova, F., & De Nicolo, G. (2002). Monetary disturbances matter for business fluctuations in the G-7. *Journal of Monetary Economics*, *49*(6), 1131-1159.

Diebold, F. X., Rudebusch, G. D., & Aruoba, S. B. (2006). The macroeconomy and the yield curve: a dynamic latent factor approach. *Journal of econometrics*, *131*(1), 309-338.

Duffee, G. R. (2002). Term premia and interest rate forecasts in affine models. *The Journal of Finance*, *57*(1), 405-443.

Härdle, W. K., & Majer, P. (2012). Yield Curve Modeling and Forecasting using Semiparametric Factor Dynamics.

Hautsch, N., & Ou, Y. (2012). Analyzing interest rate risk: Stochastic volatility in the term structure of government bond yields. *Journal of Banking & Finance*, *36*(11), 2988-3007.

Hördahl, P., Tristani, O., & Vestin, D. (2008). The yield curve and macroeconomic dynamics. *The Economic Journal*, *118*(533), 1937-1970.

Nelson, C. R., & Siegel, A. F. AF (1987): Parsimonious Modelling of Yield Curves. *The Journal of Business*, *60*, 4.

Pelagatti, M. M. (2015). *Time series modelling with unobserved components*. CRC Press.

Rudebusch, G. D., & Wu, T. (2008). A Macro-Finance Model of the Term Structure, Monetary Policy and the Economy. *The Economic Journal*, *118*(530), 906-926.