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An affine multifactor model with macro factors for the German term structure: changing results during the recent crises

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Abstract

Using arbitrage-free affine models, we analyze the dynamics of German bond yields and risk premia for the period 1999 to 2010 (EMU). We estimate two model specifications, one with only latent factors, and another one with a Taylor-type rule comprising a price and a real activity factor drawn from a large macroeconomic data set as additional driving forces. We apply several statistical methods to select those time series from which the factors are actually extracted. The macroeconomic factors, notably the real activity factor, help to improve the fit of the model. Moreover, the inclusion of the macroeconomic factors allows us to analyze their effect on the risk aversion of market participants. Looking at the impact of the recent crises, we see that particularly the market prices of risk for the real activity and the price factor changed most dramatically. Offsetting safe haven flows, which affect shorter maturities in particular, explain why yield risk premia increase less at the short end as compared to longer maturities in times of crisis. A liquidity stress factor included in the macro model mirrors this slope influencing effect of the safe haven flows and leads to smoother forward rates for yield risk premia.

JEL Classification: E43, E52, G12

Keywords: Affine term structure models, macroeconomic factors, risk premia, liquidity, financial crisis.

Non-technical summary

The previous subprime and financial crisis and the current sovereign debt crisis on the one hand and an unconventional monetary policy setting that is much more directed towards long-term capital market rates on the other hand have encouraged the interest in the fundamental driving forces of long-term interest rates and the overall development of the term structure of interest rates. The main objective of this paper is to explain term structure movements and the related yield risk premia using macroeconomic factors, particularly in times of crisis. Risk premia comprising compensation for inflation risk, for real risk and for liquidity of the underlying securities are an important part of the yields of German government bonds.

We apply a widely used macro finance modeling framework. It contains statistical factors and two macroeconomic factors which summarize information on output and price developments. The model, therefore, allows a fundamental interpretation of term structure developments, as, for instance, a change in the risk aversion of market participants can be traced back to changes in the macroeconomic factors. We apply a novel estimation approach and use the model to estimate the German term structure of interest rates for the time from 1999 to 2010. We use information from a large macroeconomic data set consisting of German, euro-area, US and other international time series. By means of several statistical procedures, we select those series from the data set that are actually of use for our yield curve analysis. The price factor reflects movements in goods-, asset- and commodity prices as well as financial variables and the output factor condenses data from series on production, the labor market, income and surveys. Furthermore, we investigate how peculiarities of the term structure in times of crisis can be explained by a factor that represents liquidity stress on bond markets.

The macroeconomic factors, notably the output factor, improve the fit of the model estimates and explain a substantial amount of variation in (future) bond yields. Even though short-lived variations in the term structure are mainly driven by changes in the statistical factors, longer-term developments are more grounded within fundamental factors such as business cycle and growth trends. The impact of the recent financial crises becomes obvious in an increased market price of risk. Especially the market prices of risk of the macroeconomic factors exhibit a clear reaction to the crises. Offsetting flows into safe government bonds (safe haven flows), which affect shorter maturities in particular, explain why yield risk premia increase less at the short end as compared to longer maturities. The liquidity stress factor mirrors this effect particularly in times of crisis and leads to smoother risk premia. With the help of the liquidity stress factor, one can thus derive the effects of the real activity factor on the term structure of interest rates without inference from safe haven flows in times of crisis.

Nicht-technische Zusammenfassung

Die vergangene Subprime- und Finanzkrise und die andauernde Staatsschuldenkrise einerseits sowie ein stärker auf Kapitalmarktzinsen ausgerichteter Einsatz von unkonventionellen geldpolitischen Instrumenten andererseits haben das Interesse am Einfluss von Fundamentalfaktoren auf Langfristzinsen und die Entwicklung der gesamten Zinsstruktur gestärkt. Ziel dieser Studie ist es, mittels makroökonomischer Faktoren Zinsstrukturänderungen insbesondere auch in Krisenzeiten zu erklären und die aus ihr abgeleiteten Risikoprämien für Anleiherenditen zu bestimmen, denn Risikoprämien sind ein wichtiger Teil der Renditen von deutschen Staatsanleihen. Sie sind definiert als Kompensation für Inflationsrisiken, realwirtschaftliche Risiken und für die (Il)Liquidität der zugrundeliegenden Wertpapiere.

Wir greifen auf einen weit verbreiteten Makro-Finanzierungs-Modellrahmen zurück. Dieser beinhaltet sowohl statistische Faktoren als auch zwei makroökonomische Faktoren, welche Informationen über die Realwirtschaft und die Preisentwicklung enthalten. Das Modell erlaubt deshalb eine fundamentale Interpretation von Zinsstrukturentwicklungen, indem etwa von Änderungen der Makrofaktoren eine geänderte Risikoaversion der Marktteilnehmer abgeleitet werden kann. Wir wenden eine neue Schätzmethode an und schätzen mit dem Modell die deutsche Zinsstrukturkurve für den Zeitraum 1999 bis 2010. Wir nutzen dafür Informationen einer breiten makroökonomischen Datenbasis aus deutschen, europäischen, US-amerikanischen und anderen internationalen Datenreihen. Mit Hilfe verschiedener statistischer Methoden ermitteln wir diejenigen makroökonomischen Zeitreihen, die letztendlich für unsere Analyse der deutschen Zinsstruktur von Nutzen sein können. Der Preisfaktor spiegelt Bewegungen in Güter-, Vermögens- und Rohstoffpreisen und Finanzvariablen wider, der realwirtschatliche Faktor umfasst Produktions-, Arbeitsmarkt- und Einkommensentwicklungen sowie Umfragedaten. Zusätzlich analysieren wir, wie sich mit einem Faktor, der Liquiditätsstress an den Anleihemärkten signalisiert, außergewöhnliche Merkmale der Zinsstruktur in Krisenzeiten erklären lassen.

Die Makrofaktoren, insbesondere der realwirtschaftliche Faktor, verbessern die Anpassungsqualität des Modells und erklären Bewegungen von (zukünftigen) Zinsen zu einem guten Teil. Auch wenn die kurzfristigen Veränderungen der Zinsstruktur im Wesentlichen durch die statistischen Faktoren getrieben werden, so sind längerfristige Entwicklungen doch in Fundamentalfaktoren begründet, welche den Konjunkturzyklus oder Wachstumstrends widerspiegeln. Der Einfluss der jüngsten Krisen zeigt sich in den gestiegenen Marktrisikopreisen, insbesondere in denen für das makroökonomische Risiko. Der Zufluss von Mitteln in liquide und sichere Staatsanleihen (Safe-Haven-Flows), insbesondere in kürzerfristige Laufzeiten, erklärt warum die aus den Zinsen abgeleiteten Risikoprämien am langen Ende stärker als im kurzfristigen Bereich angestiegen sind. Der Liquiditätsstressfaktor nimmt diesen Effekt besonders während Krisenzeiten auf und ermöglicht damit die Ableitung von weniger sprunghaften Risikoprämien. Damit können auch während Krisenzeiten die Effekte des realwirtschaftlichen Faktors auf die Zinsstruktur ohne die Verzerrungen von Safe-Haven-Flows dargestellt werden.

Contents

An affine multifactor model with macro factors for the German term structure: Changing results during the recent crises [1]

1 Introduction

The growing influence of the level and the development of long-term interest rates in fiscal and monetary policy has boosted the research on government bond yields especially during the recent crises. What drives the whole term structure and what is its relation to policy controlled short-term rates and the state of the real economy are questions that came to the fore not least owing to unconventional monetary policy settings that are much more directed to long-term capital market rates. How can fundamental influences incorporated in macroeconomic variables be taken into account in bond yield estimations, given that these could already be well described by unobservable, latent factors which determine the level, slope and curvature of the term structure?[2] And are the fundamental macroeconomic influences of higher relevance during the recent crises? How can those time series be determined from a huge macroeconomic data set that should be incorporated in the term structure estimation? And which alternative factor can be used to explain term structure dynamics in times of crisis? These are key questions that the paper tries to answer.

To shed a little more light on the relation of the fundamental factors to the term structure and the yield risk premia, we choose a setup that explicitly incorporates a price and a real activity factor as additional driving forces besides three latent factors. Incorporating macro factors by formulating monetary policy rules seems to be a promising starting point since long-term interest rates depend on expectations of future short-term interest rates, which are in turn influenced by the response of central banks to developments in the real economy. This response can be formulated in a Taylor-type monetary policy rule following Taylor (1999) and Smith and Taylor (2009). Whereas common Taylor-type rules consist of inflation and output gap as parameters to respond to, it is obvious that most central banks include a broader set of macroeconomic variables in their assessment of the state of the economy, of the risks to price and of the financial stability. We therefore employ a vast set of macro variables (see Section 3.2) which we condense by means of shrinkage and factor analysis to two macro factors which we call price and real activity factors. This means that the price factor is drawn from a set of time series reflecting nominal or price developments which have been selected on account of their relation to the short rate and the term structure. The same applies analogously for the real activity factor. Classical factor literature has shown that a large number of variables condensed into a small set of factors is effective in explaining and forecasting macro variables (Eickmeier and Ziegler (2008)). We apply that result in formulating our structural policy rule.

[1]Arne Halberstadt and Jelena Stapf, Deutsche Bundesbank, e-mail: arne.halberstadt@bundesbank.de, jelena.stapf@bundesbank.de. The views expressed here are those of the authors and not necessarily those of the Deutsche Bundesbank. We thank Klaus Adam, Michael Fischer, Felix Geiger, Klemens Hauzenberger, Leo Krippner, Thomas Laubach, Wolfgang Lemke, Christian Schumacher, Thomas Werner and seminar participants of the 2nd Bundesbank Zinsstrukturworkshop, the ICMAIF 2012, the CEF 2012 and the EEA 2012 for helpful discussions. We are grateful to Sandra Eickmeier for supplying the Matlab codes for the macro factor selection procedure and to Domenico Giannone for supplying the US data set. The usual disclaimer applies.

[2]See, e.g., Litterman and Scheinkman (1991) or Dai and Singleton (2000).

The liquidity and volatility of assets have increasingly come to the fore since the onset of the recent crisis. In an attempt to capture the liquidity of government bonds we substitute the price factor for a liquidity stress factor drawn from an array of time series signaling the liquidity and volatility of the German fixed income market. If this liquidity stress factor captures effects of the crisis efficiently, it can improve estimations of term structure effects in response to the real activity factor. Indeed, we can find that the liquidity stress factor influences the slope of risk premia attached to the term structure of interest rates. Risk premia comprising compensation for delay in consumption for inflation risk, for real risk and for liquidity of the underlying securities explain an important part of the yields of German government bonds. Diverging developments across maturities do influence the slope of the yield curve and therefore the transmission of monetary impulses, again especially in times of crisis.

This paper applies a new estimation approach for affine term structure models to German data in shifting from traditional maximum likelihood to minimum chi square estimations following Hamilton and Wu (2012a). In order to keep the model simple, we choose a similar setup to that which Smith and Taylor (2009) and, in particular, Ang and Piazzesi (2003) employ for the US. The fast-growing number of affine term structure models with macroeconomic variables in the literature can be classified - amongst other things - according to how the "macroeconomy" is specified. Gürkaynak and Wright (2010) provide a good overview of recent research. We apply a reduced form VAR representation of the macroeconomic data which started with a paper from Ang and Piazzesi (2003) for US data. They also use a principal component analysis for extracting macro factors but from a much more contained data set. Papers dealing with US data often expand the macro part of the models from simple Taylor rules to a more structural framework (e.g. Dewachter and Lyrio (2006), Rudebusch and Wu (2008) or Bekaert, Cho, and Moreno (2010)). Applications for German data mostly impose less structure on the macro variables. The latter comprise an ex-post correlation of macro factors with unobservable factors (Cassola and Luis (2003)), a Taylor rule with inflation and the output gap (Lemke and Stapf (2006)) and a canonical representation of the term structure which includes inflation, the output gap and three unobservable factors in the short rate (Pericoli and Taboga (2006)). Hördahl, Tristani, and Vestin (2006) use German data as an application and allow for explicit feedbacks from the short rate to macro factors, namely inflation and output gap, and therefore obtain an endogenous description of the dynamics of the short rate.

The remainder of the paper is organized as follows. The next section outlines the model specifications, followed by a description of the data in Section 3. The influence of macro variables on the term structure, risk premia developments during the crisis, and the role of a liquidity stress factor are subsumed under empirical results (Section 4). Section 5 discusses robustness checks. The last section concludes.

2 Model specification

We apply an affine term structure model to estimate the yields given two different sets of state variables. One set contains only latent factors and the other additionally contains two principal components which summarize macroeconomic information. In general, we adopt the modeling approach of Ang and Piazzesi (2003). However, we estimate the model with an approach that was

recently proposed by Hamilton and Wu (2012a)[3]. Their method is based on minimum chi square estimation (MCSE) instead of the commonly used maximum likelihood. Moreover, they estimate the reduced form parameters with least squares methods and then use those estimates to infer the structural parameters. This has at least two advantages. First, it lowers the computational burden significantly as one does not have to try several different sets of starting values. Second, the application of MCSE makes it possible to detect whether an optimum that was found is indeed global or rather local. We refer to the papers of Ang and Piazzesi (2003) and Hamilton and Wu (2012a) for thorough discussions of their modeling approaches. Here we present the equations of Hamilton and Wu (2012a) that are most relevant for our model, and widely retain their notation to ease the comparison.
The state variables represent the information about the economy that the investors use to price the bonds. They follow a vector autoregressive (VAR) process:

$$F_{t+1} = c^j + \rho^j F_t + \Sigma u^j_{t+1}, \tag{2.1}$$

with u^j_{t+1} being a standard Gaussian error term. As the bond yields will depend on the investors' assessment of the economic dynamics, this assessment depends on the risk appetite of the investors. We thus consider two representations of equation (2.1) which pin down two different specifications of certain risk measures: the risk-neutral pricing measure, $j = Q$, and the pricing measure of a risk-averse investor, $j = P$, which is sometimes called the physical probability measure. The relation of the parameter estimates of these specifications is established through the market price of risk. In general, those prices can be understood as the premia that a risk-averse investor demands over the risk-neutral price. The time-varying market prices of risk, λ_t, are affine functions of the underlying state variables F_t:

$$\lambda_t = \lambda + \Lambda F_t. \tag{2.2}$$

The relation of the parameters of the P-measure to the Q-measure are then:

$$c^Q = c^P - \Sigma\lambda, \tag{2.3}$$

$$\rho^Q = \rho^P - \Sigma\Lambda. \tag{2.4}$$

It is assumed that the short-rate is also an affine function of the state variables:

$$r_t = \delta_0 + \delta_1' F_t. \tag{2.5}$$

Given the estimates of the short-rate parameters together with those of the VAR parameters, we obtain the yield of a n-period zero coupon bond:

$$y^n_t = a_n + b_n' F_t, \tag{2.6}$$

where:

$$\begin{aligned} a_n \quad = \quad & \delta_0 + (b_1' + 2b_2' + ... + (n-1)b_{n-1}')c^Q/n - \\ & (b_1'\Sigma\Sigma' b_1 + 2^2 b_2'\Sigma\Sigma' b_2 + ... + (n-1)^2 b_{n-1}'\Sigma\Sigma' b_{n-1})/2n, \end{aligned} \tag{2.7}$$

$$b_n = \frac{1}{n}[I_m + \rho^{Q'} + ... + (\rho^{Q'})^{n-1}]\delta_1. \tag{2.8}$$

[3] We used the Matlab code for this approach that was kindly provided by James Hamilton and Jing Cynthia Wu on their web site, e.g.: *http://dss.ucsd.edu/~jhamilto/software.htm#atsm*.

We can use a_n and b_n to derive yield risk premia. Yield risk premia are the difference between the observed yields and the hypothetical yields given by the expectations hypothesis:

$$\begin{aligned} yrp_t^n &= \frac{1}{n}\sum_{i=1}^{n-1}(\ln P_t^i - \ln P_t^{i+1} - E_t(y_{t+i}^1)) \\ &= a_n + b_n' X_t - a_1 - b_1'(I_N - \mathcal{K}^n)(I_N - \mathcal{K})^{-1} X_t. \end{aligned} \tag{2.9}$$

P_t^n is the price of a bond that is an exponential function of the according yield, $P_t^n = \exp(-ny_t^n)$. $\mathcal{K}$ is the coefficient matrix of a VAR(1) of the state variables X_t without intercept. N, the size of the unity matrices, is the number of all factors used as state variables.

Given this general model description, let us now consider the specification for the approach with solely latent factors. In line with various contributions to the literature, we construct $N_l = 3$ latent factors from a set of three representative maturities which are assumed to be observed without error. This method, which is also applied by Hamilton and Wu (2012a), was originally proposed by Chen and Scott (1993). The choice of which maturity is measured with error and which not can have consequences for the estimation (see, for example, Hamilton and Wu (2012b)). However, our choice of the maturity sets is driven by our particular interest in obtaining a very good estimate of the 10-year yield. Hence, we assume that yields maturing in 12 months, and also 5 and 10 years are priced with error ($Y_t^2 = (y_t^{12}, y_t^{60}, y_t^{120})'$), while the maturities of 1 month and 2 and 11 years are priced without error ($Y_t^2 = (y_t^1, y_t^{24}, y_t^{132})'$). The inclusion of the 11-years yield in this subset supports the meaning of the long end of the term structure for the latent factors. Overall, we thus have six different maturities, from which $N_e = 3$ are priced with error. Hence, again following Hamilton and Wu's model description, equation (2.6) becomes:

$$\begin{bmatrix} y_t^1 \\ y_t^{24} \\ y_t^{132} \\ y_t^{12} \\ y_t^{60} \\ y_t^{120} \end{bmatrix} = \begin{bmatrix} a_1 \\ a_{24} \\ a_{132} \\ a_{12} \\ a_{60} \\ a_{120} \end{bmatrix} + \begin{bmatrix} b_1' \\ b_{24}' \\ b_{132}' \\ b_{12}' \\ b_{60}' \\ b_{120}' \end{bmatrix} F_t + \begin{bmatrix} \underset{N_l \times N_e}{0} \\ \underset{N_e \times N_e}{\Sigma_e} \end{bmatrix} u_t^e, \tag{2.10}$$

where the latent factors F_t are inverted from the blocks of equation (2.10) that are related to the yield subset that is observed without error:

$$F_t = B_1^{-1}(Y_t^1 - A_1). \tag{2.11}$$

Hamilton and Wu (2012a) apply some normalization restrictions on the parameters of the approach which we maintain, i.e. $\Sigma = I_{Nl}$, $\delta_1 \geq 0$, $c^P = 0$, and ρ^Q is lower triangular.

Let us now consider the second set of state variables, a macro finance model with single lag: Here, the factor matrix F_t contains $N_l = 3$ latent and $N_m = 2$ observed variables, $F_t = (f_t^m, f_t^l)$. The dynamics of the factors follow a VAR(1) of the form of equation (2.1), namely:

$$\begin{aligned} f_t^m &= c_m^j + \rho_{mm}^j f_{t-1}^m + \rho_{ml}^j f_{t-1}^l + \Sigma_{mm} u_t^{jm}, \\ f_t^l &= c_l^j + \rho_{lm}^j f_{t-1}^m + \rho_{ll}^j f_{t-1}^l + \Sigma_{ll} u_t^{jl}. \end{aligned} \tag{2.12}$$

Similarly, the short rate is given by:

$$r_t = \delta_0 + \delta_{1m}' f_t^m + \delta_{1l}' f_t^l. \tag{2.13}$$

Again, we maintain the parameter restrictions proposed by Hamilton and Wu (2012a), i.e. $\Sigma_{lm} = 0$, $\Sigma_{ll} = I_{Nl}$, $\delta_{1l} \geq 0$, $c_l^Q = 0$, and Σ_{mm} is lower triangular. Note that this set of restrictions is in part a deviation from Ang and Piazzesi (2003), as, for example, independence of the latent factors and the macroeconomic factors is not imposed by the assumption of a block-diagonal form of ρ_{lm}^P and ρ_{ml}^P under the physical measure. As already pointed out by Pericoli and Taboga (2006), such a restriction is both in its economic implication very strong and for the structure of the model overidentifying.
The reduced form parameters, i.e. the parameters of a restricted vector autoregression for the yields, are collected in vector π and can be conveniently estimated by least squares methods. Given $\hat{\pi}$, the structural parameter vector θ can then be estimated by minimum chi square. The MCSE estimator is based on the assumption that the reduced form parameters coincide with a function of the structural parameters, $\pi = g(\theta)$. The MCSE is then given by:

$$\min_{\theta} \; T(\hat{\pi} - g(\theta))' R(\hat{\pi} - g(\theta)), \tag{2.14}$$

where R is the information matrix of the full information maximum likelihood function $\mathcal{L}(\theta; Y)$. The minimal value that is found by this estimator can then be evaluated by the chi square distribution.[4]

3 Data

3.1 Yields

Our data set runs from January 1999 to December 2010. We use end-of-month yields on (notional) German zero-coupon bonds with maturities of 1, 2, 5, 10, and 11 years. The yields are estimated using the parametric Nelson-Siegel-Svensson method and based on German federal securities with a residual maturity of at least three months and up to 30 years. Concerning the choice of a maturity to support the long-end of the yield curve, the German government just issues bonds with initial maturities of ten and 30 years. Using a 30 year bond would imply vast projections of monthly parameter values into the future. We therefore decided to include the nearest maturity to the ten-year bonds in the estimation. Bonds with residual maturities of 11 years are not significantly less traded compared to bonds with residual maturities of 12 or 15 years according to bid-ask spreads. Yet, rerunning the estimations with the latter maturities instead of 11-year bonds does not change the results by much. Notwithstanding that we describe the period of a common euro-area currency and monetary policy, there is no single debt security market for central governments. Using an aggregated euro-area long-term yield, whatever the weighting scheme might be, would hide the fact that yields on national government issues might be driven by national demand and supply factors, and this is likely to be the case to an even greater extent in the current sovereign debt crisis. Nevertheless, we acknowledge that a significant proportion of German federal securities are traded and held outside the country (numbers range from 74% to 86% according to sources: Bundesbank, securities deposit statistics and Havers Analytics, published in Singhania (2011), respectively) and are therefore influenced

[4]Hamilton and Wu (2012a) provide details on the derivation, asymptotic properties and evaluation of this estimator. They also explicitly derive the application of the model for the latent and the macro factor approach.

by non-national factors. This is especially the case for macroeconomic variables which influence interest rates. An Italian investor, for example, who holds a Bundesanleihe (Bund) might look more on the Italian price level instead of the German one since he is prone to spend the proceeds from his investment in Italy. The same rationale might apply to other variables and other countries inside and outside of the euro area.

We do not use yields on government bonds for the shortest maturity, i.e. the 1-month interest rate. This is due to the fact that money market rates dominate this segment of the maturity spectrum. Federal debt securities are rarely traded when close to expiry. 1-month yields which can be extracted through the parameters of the Nelson-Siegel-Svensson estimation in fact show a considerable degree of unwarranted volatility (see Figure 1, left hand panel, black line). Yet, the obvious solution of using the 1-month Euro Interbank Offered Rate (Euribor, dashed line), which dates back to 1999, highlights some caveats in the estimation during the crisis period. In 2007, when the banking crisis developed, counterparties requested a higher compensation when lending money even for a short period of time on account of fears of not getting their money back. This was the time when secured lending gained importance. The Euro Repo rate (Eurepo, thin line), first published in March 2002, reflects the lending rate against the best available collateral averaged from quotes of 36 panel banks. It might better reflect the notion of a risk-free interest rate in times of possible defaults of counterparties. The increasing and volatile spread between secured and unsecured money market rates translates into diverging yield risk (term) premia in the estimation of an affine term structure model with only latent factors (see Figure 1, right hand panel). The term premia for short or long-term yields with an unsecured lending rate (bold line) is more contained compared to that of an estimation with a secured 1-month rate (dotted line). This lets us conclude that starting with a risky asset at the short-end of the yield curve depresses risk premia along the yield curve and blurs future interest rate expectations. We therefore use the Euribor rate from the start of the EMU up to 2002 and the Eurepo 1-month rate from March 2002 onwards (as soon as it became available). Since both rates run closely together during the first time period, with a maximum spread of 6 basis points, we do not judge the change in the rate as harmful for the estimation.

Looking at the difference between the yield risk premia on bond yields estimated with a secured

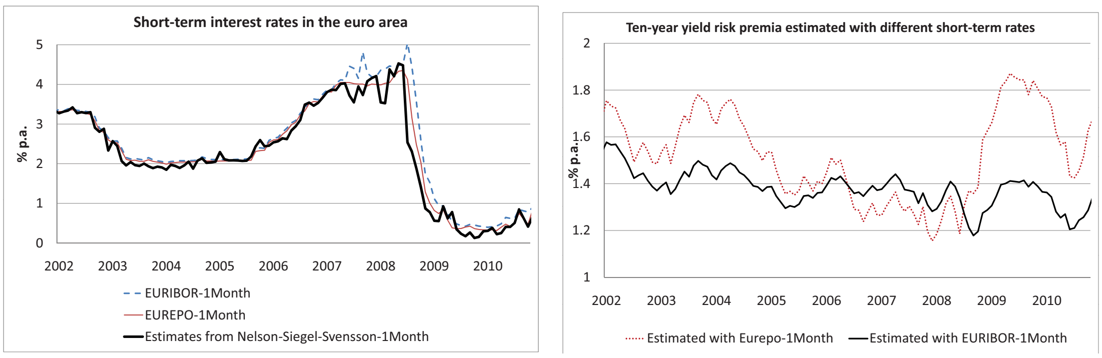


Figure 1: Different short-term rates in the euro area and impact on the estimation of yield risk premia.

and an unsecured short-term rate, one might be tempted to term this distance an indicator for the fragility of euro-area banks. The distrust of euro-area banks to lend each other money on an unsecured basis was high during the burst of the dot com bubble, the fall of Lehman Brothers Inc., and the recent sovereign debt crisis. In between there was a calm period where both risk premia curves run closely together.

3.2 Macro variables

Movements of the yield curve can be described fairly well with latent stochastic factors. Yet, in order to obtain a more structural interpretation of what drives the yield curve and a formal link to the real economy we include macro factors in the estimation. We started with a data set of 451 time series and grouped them into different macro categories. These comprise balance of payments developments, construction, capacity utilization, GDP (expenditure and gross value added), housing, industrial production, labor market, orders, surveys and world macro factors as categories focusing on real activity developments, and good prices, financial variables, bond market liquidity, monetary aggregates and raw material prices as categories reflecting nominal developments. Most of the categories contain German, euro-area and US data series. On account of having a balanced data set, we restrict the time period to between January 1999 and December 2010, for which all variables were available. We transformed all series into stationary time series by means of differencing. We further standardized them to have a unit variance and zero mean and removed outliers following Stock and Watson (2005).

Since the number of factors in a term structure model is restricted at least by the number of yields included, we shrank the data set in several ways. From an economic point of view, we are interested in time series that provide as much explanation for the development of the short rate and the yield curve overall as possible without imposing too much structure on the relationship between macro variables and yields. Compared to a classical Taylor rule, a reaction function of the central bank to inflation and output gap developments, we tried a more bottom-up approach in which we selected those time series that are of interest for term structure developments out of a broad data set. First, we excluded categories whose principal components did not help to explain the short-term interest rate and the level of the yield curve [5] to a significant amount in univariate regressions. We grouped the residual categories into a price group (goods prices, raw material prices, asset prices and other financial variables) and a real activity group (GDP, labor market, industrial production, capacity utilization and surveys). We used a pooled approach to reduce the number of variables remaining in the groups on account of getting rid of variables which have low correlation with the target variable - the short-term interest rate - and which have a strong idiosyncratic component, e.g. do not have a strong factor structure.[6] We closely follow Eickmeier and Ng (2010) and Groen and Kapetanios (2008) in applying several shrinkage procedures. The methods used comprise hard and soft thresholding in dropping variables which are not significant in bivariate regressions using LARS [7], removing variables with low commonalities, down weighting variables with the inverse of the standard deviation of their idiosyncratic component and removing variables which have idiosyncratic errors that are highly correlated with other variables idiosyncratic errors. We ended up with 45 variables in the real activity and 16 variables in the price group respectively (data series description and transformation classification by Stock and Watson can be seen in the Appendix in Table A.4). We draw the first principal component (PC) out of the remaining time series in each group. The PC estimator

[5] We used the first latent factor of the yields-only model which is termed the level factor.

[6] Kuzin, Marcellino, and Schuhmacher (2009) show that in the presence of model uncertainty using a pooled approach over a variety of models outperforms model selection.

[7] Least angle regression, see Efron, Hastie, Johnstone, and Tibshirani (2004).

shows the common component of all variables in the group and is consistent for the factors even if the factor loadings vary somewhat over time, as has been shown by Stock and Watson (2008). All in all our two macro factors - real activity and prices - feature on the one hand a high proportion of variance explained of the underlying time series (38% and 74%, respectively) and on the other hand still have a meaningful interpretation in terms of being a factor driven by goods and asset prices or by labor market and output developments as well as by a forward looking assessment of the business cycle development (see Table A-1 in the Appendix). We additionally computed a liquidity stress factor with the notion to influence the slope rather than the level of bond yields. It is derived from a liquidity and volatility series data set with KfW-Bund spreads, bid-ask spreads of Bunds, volatilities and implied volatilities of interest rate bearing instruments and of spreads of secured and unsecured lending, with each measure computed for longer and shorter maturities. A plot of all three factors is provided in the Appendix (Figure A-1).
For all macro factors the null of a unit root is rejected with a standard ADF test at least at the 5% level. Also the short rate, which is used as a regressor in preliminary analyses but will not enter our affine term structure model as a state variable, is stationary for the considered sample period. The macro factors are drawn from different subsets of time series and can therefore be correlated. Our price and real activity factors show a correlation of 0.34, while the correlation between the real activity and the liquidity stress factor is -0.08.

4 Empirical results

4.1 Influence of macro variables on the term structure

Comparing the yield estimates resulting from the yields-only model and the macro model allows us to shed some light on the relevance of macroeconomic information for the yield estimation. Overall, the root mean squared error (RMSE) of the yield estimates is indeed smaller for the macro model ($RMSE^{mf} = 0.03$) compared to the yields-only model ($RMSE^{lat} = 0.04$), yet yields are fitted comparatively well with both models. Table 1 provides more details for this result, particularly maturity-specific RMSEs. One can see that the RMSEs are higher for short maturities than for longer maturities in both setups. As explained in Section 2, this pattern may be driven by our choice of maturities and the incorporation of Euribor and Eurepo as short rates. However, the results also indicate that the macroeconomic factors are of some relevance for the yield estimation. This result is in line with other papers including macro factors which enter directly as risk factors, such as in Ang and Piazzesi (2003), Ang, Dong, and Piazzesi (2007), Rudebusch and Wu (2008), Smith and Taylor (2009), and Bibkov and Chernov (2010). Since the model is estimated over the whole sample period, we are of course void of detecting structural breaks leading to changes in the relevance of macro factors. As a first approach to this issue we check for the explanatory power of our macro factors by means of a sample split in the robustness check section.

At least in the long run, one expects yield dynamics anyhow to be related to macroeconomic fundamentals. Hence, if our macroeconomic factors are indeed able to capture information about those fundamentals, they should be correlated to the yields. For both the macroeconomic and the latent factors, Table 2 provides these correlations to the yields. Not surprisingly, the highest values for the contemporaneous correlation emerge for the latent factors. In fact, standard term

Maturity	Macro Model	Yields-Only
$y^{(12)}$	0.05	0.06
$y^{(60)}$	0.03	0.04
$y^{(120)}$	0.02	0.02

Table 1: Root mean squared errors of yield estimates that are priced with error for the macro model and yields-only model (sample: July 1999 to December 2010).

	$Y(12m)$	$Y(60m)$	$Y(120m)$	$YRP(12m)$	$YRP(60m)$	$YRP(120m)$
Contemporaneously:						
Real activity factor	0.34	0.26	0.11	-0.46	-0.40	-0.38
Price factor	0.08	0.09	0.06	-0.19	-0.22	-0.22
1st Latent	0.84	0.95	0.98	-0.82	-0.87	-0.88
2nd Latent	0.40	0.27	0.00	-0.42	-0.40	-0.38
3rd Latent	0.96	0.84	0.70	-0.91	-0.80	-0.79
12m Lagged:						
Real activity factor	0.70	0.56	0.39	-0.63	-0.54	-0.53
Price factor	0.09	0.04	-0.00	-0.05	0.00	0.00
1st Latent	0.35	0.53	0.71	-0.28	-0.36	-0.39
2nd Latent	0.39	0.21	0.03	-0.35	-0.23	-0.21
3rd Latent	0.41	0.54	0.65	-0.32	-0.39	-0.42

Table 2: Correlation of the yields that are assumed to be measured with error (left hand panel) and the corresponding yield risk premia (right hand panel) to the model factors for the sample from July 1999 to December 2010.

structure estimations following Dai and Singleton (2000) featuring just two or three latent factors are capable of reproducing the cross section of the term structure quite well. Concordantly, a principal component analysis of the yields used in our estimation shows a high proportion of variance explained for the first PC and the second PC (89% and 9%, respectively), a moderate for the third PC (1%), whereas it falls under 0.1% for all subsequent PCs.

However, when lagging the macroeconomic factors by 12 months, the real activity factor becomes most correlated with the yields over nearly all maturities. This seems to provide evidence that macro factors are important to forecast yields and hence can be used to represent information that is unspanned by the cross section of yields. This is in line with Joslin, Priebsch, and Singleton (2010) and Ludvigson and Ng (2009) who showed that so-called unspanned macro risks that have virtually no effect on the current term structure may explain a substantial proportion of the variation of forward term premia and excess bond returns (see also Cochrane and Piazzesi (2005) and Duffee (2011)). So even though the cross section of yields might be fairly well described by latent factors, macro risks that could, for example, be offset by changes in the term premia and therefore cancel out in the cross-sectional analysis of the term structure bear information for future yields. Although our estimated yield risk premia behave somewhat counter cyclical to the macro factors (see Table 2, right hand panel) they do not run in exactly opposite directions which refrained us from implementing a model with unspanned macro factors in a first step. Yet, analyzing the macroeconomic impact on the term structure further might well result in setting up a model where macro factors influence only the physical law of motion of the state vector and not the risk-neutral one in future research.

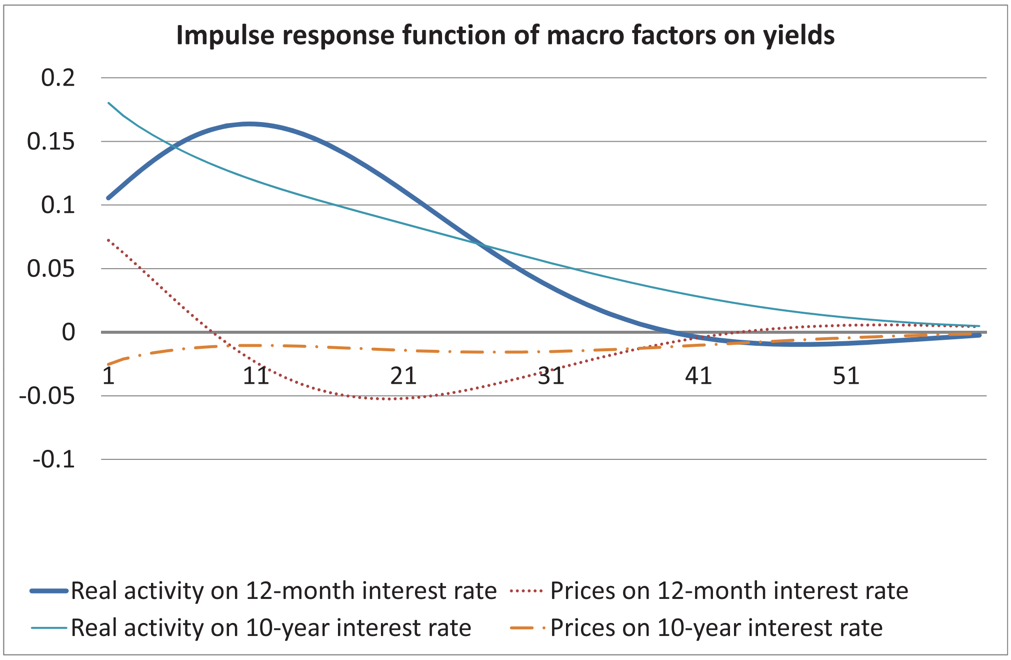


Figure 2: One standard deviation shock on the real activity and the price factor. The responses of the x-month interest rate are calculated from coefficient estimates for the sample July 1999 to December 2010, and they are measured in % p.a. on the y-axis. Time is measured in months on the x-axis.

We also derive impulse response functions which show how a shock on a factor affects the yields.[8] A one-standard deviation shock to the real activity factor seems to have stronger and more persistent effects compared to innovations in the price factor, especially for longer maturities (see Figure 2). Whereas initial responses of the real activity and price shocks are quite similar on 12-month yields, they differ significantly for long-term yields. The response of the short rate on a real activity shock shows a hump-shaped pattern, peaks after 12 months and dies out after around three years (bold line). A ten-year yield which by definition covers expected future short-term yields, shows the full impact of the shock nearly instantaneously and dies out more slowly (thin line). Unexpected changes in labor market conditions, GDP growth rates or capacity utilization rates inflict persistent effects on yields. This is somewhat in line with the results Ang and Piazzesi (2003) derived for US data and Hördahl et al. (2006) and Lemke and Stapf (2006) derived for German data before the crises periods. Reactions to innovations in the price factor declined much faster for the 12-month yield and are insignificant for the 10-year yield (dotted and dashed line, respectively). This is in contrast to the higher and more persistent impact of inflation shocks in the US data. Yet, Lemke and Stapf (2006) also find less pronounced responses of German yields to inflation shocks and Hördahl et al. (2006) of yields to monetary policy shocks, which is somewhat mirrored in studies finding low coefficients for inflation when

[8]On account of having clearly interpretable coefficients for the impulse responses, we used a partial Gram-Schmidt orthogonalization to correct for correlation between the real activity factor and the price factor and put most weight on the price factor (see Burgill (2011)). Results with the orthogonalized factor do not differ much qualitatively from those with the original factors. For details on the derivation of impulse response functions in an ATS model, see e.g. Ang and Piazzesi (2003).

estimating Taylor rules for the euro area (see e.g. Gerdesmeier and Roffia (2004)). One possible interpretation for the German result could be that market participants see deviations from the price factor as rather short lived. Consequently they do not adjust expectations on future short-term yields and therefore on long-term yields by much. Bearing in mind that the price factor captures not only goods but financial assets and raw material prices as well, we compare its low impact with the small wealth effects of asset price changes which are traditionally assumed to be very low in Germany (see Hamburg, Hoffmann, and Keller (2005)). Since asset price changes do not affect income and consumption by much, they might not affect interest rates by much either.

4.2 Risk premia developments during the crisis

For the macro model, we now consider the market prices of risk. Those prices can be understood as the premia that a risk-averse investor demands over the risk-neutral price. In Figure 3, the market prices of risk for every state variable are plotted. They indicate how a shock to the factors, namely u_t in equation (2.1), affects the yields. Note that the very value of the risk prices can hardly be interpreted. The meaning depends on how well the underlying factors are identified. As we use principal components that were extracted from standardized, transformed data, we can only make statements on the sign and the relative change of the series over time. In this sense, Figure 3 allows us to detect remarkable changes of the risk prices over time.

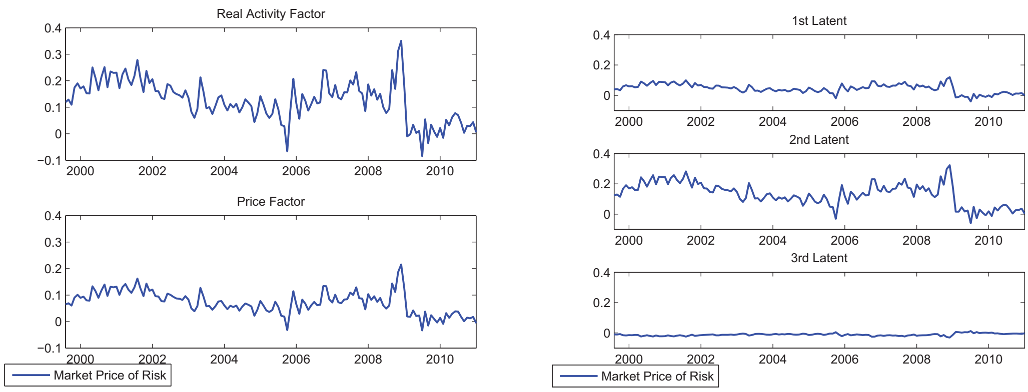


Figure 3: Market prices of risk for the factors of the macro model: All values are divided by 100.

All risk prices indicate either an all-time maximum or minimum for end-2008, thus showing a strong response to the collapse of Lehman Brothers Inc. and its aftermath. However, the premia that were paid for the underlying factor risk returned surprisingly fast to their pre-crisis levels in the following two years - except for the third latent factor. There are two possible lines of explanation for that. On a global level, the economies and especially interest rates benefitted at that time from substantial and coordinated actions from major central banks to ease liquidity problems. Additionally, in most countries fiscal stimulus packages were introduced to avoid a collapse of the real economy. Secondly, on a national level Germany recovered relatively fast from the economic downturn in the wake of the crisis owing to a quick rebound of exports, especially those directed towards fast developing countries, and a robust labor market.

Yield risk premia, on the other hand, can be derived using equation (2.9). Yield risk premia are higher for longer maturities (see Figure 4). Once again, the shift in risk premia levels since the onset of the banking and sovereign debt crisis is visible in all maturities. Especially the five-to-ten-year forward term premia [9] picked up in the year 2008 after the antecedent period of the great moderation. This is in line with a recent finding by Wright (2011), also derived from an affine term structure model with macro factors for Germany and other countries.[10] Comparing the risk premia estimates of the macro factor model with the latent factor model (see Figure 1 in Section 3.1), we see a somewhat similar development. Premia sloped downward from 2002 to 2008, increased subsequently - more pronounced in the macro model - and trended downward in end-2010. Overall, the ten year yield risk premium is smaller on average in the macro model suggesting that the macro factors which capture volatile macroeconomic and liquidity (see next Section) developments pick up in part the real fraction of the risk premium. Looking at the correlations of the factors with the yield risk premia, we see a higher impact of both macro factors (see Table 2 in Section 4.1). The correlation with the price factor becomes now significant at the 5% level. As it is in boom periods that prices and real activity go up and in bust phases that both go down, the yield risk premia exhibit some countercyclicity and therefore a certain degree of predictability (see e.g. Cochrane and Piazzesi (2005)).

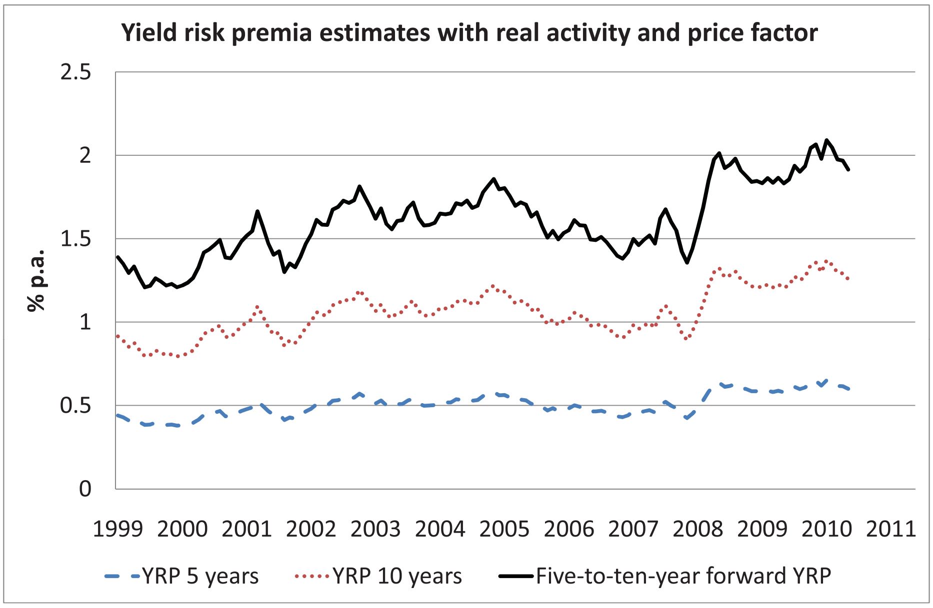


Figure 4: Yield risk premia for the maturities that are assumed to be priced with error.

Interestingly, the yield risk premia shifted more for longer maturities and therefore show a more pronounced rise in the long-term forward rate (see Figure 4). Though disruptions in the banking crisis stemmed from the money market segment with banks distrusting each other and a drying up of unsecured lending, the uncertainty of future interest rate movements and increasing macro volatility quickly spilled over to longer maturities and caused term premia to increase.

[9] The forward term premia are calculated as follows: $(yrp_t^{10y} * 10 - yrp_t^{5y} * 5)/(10 - 5)$.

[10] Wright (2011) shows overall declining German term premia - though not very pronounced compared to other countries - up to the middle of the first decade of the new millennium. We were not able to reproduce that result. This is very likely to be the case because we started our estimation in 1999, whereas his analysis started a decade earlier. The 1990s were indeed a period in which the interest rates of German Bunds were greatly influenced by the currency trouble during the ERM crisis and the Asian and Russian crises towards the end of the decade. Using a longer data sample and only a two latent factor set up, we were able to show at least a declining amplitude of term premium fluctuations up to 2007.

The distinct development of term premia of different maturities could also be an indication of investors concentrating more on shorter maturities. Consequently, the so-called safe haven flows might have hindered term premia of shorter maturities from increasing as much as longer maturities. This interpretation, which focuses on liquidity influences is explained in more detail in the next section.

4.3 Including liquidity into the model

In recent years, financial market participants have become increasingly concerned about the liquidity of assets. In times of turbulent markets, investors are willing to pay a premium for assets that can be easily sold at any time. In this section, we examine two ways to investigate the meaning of market liquidity developments for government bond yields. First, we replace our price factor in the macro model by a measure of liquidity stress. Second, we reestimate the whole macro model for the term structure using German agency bond yields instead of German government bond rates.

Bonds issued by the German Agency KfW (*Kreditanstalt für Wiederaufbau*, Reconstruction Loan Corporation) are backed by an explicit government guarantee and therefore bear the same credit risk as government bonds themselves. Yet, Bunds belong to the most liquid assets traded worldwide. They are frequently used as collateral and are deliverables for several contracts on the derivative markets. Compared to that of Bunds, KfW bonds show a far smaller issued amount outstanding (€166 bn for KfW bonds compared to €1080 bn for Bunds, respectively) and have a lower average issue volume (€1.3 bn for KfW bonds compared to €20.9 bn for Bunds with ten-year maturities, respectively). The differences in size and in usage translate into a difference in liquidity, hence the possibility to buy and sell large quantities of the security without affecting its market price (Amihud, Mendelson, and Pederson (2005)). The liquidity differential translates in turn into higher yields of KfW bonds compared to Bunds.

Figure 5 provides an overview of the five (bold line), ten (dotted line), and fifteen (dashed line) year KfW-Bund spread. The yield spreads indicate a first peak in the second half of 2000 and the beginning of 2001, when the burst of the dot-com bubble turned asset prices down. After coming down again in the following years, the spreads reached a new high at the end of 2008. The spread of shorter maturities,which in calm periods runs below that of longer maturities, picked up more in crisis periods and drifts above that of longer maturities. This feature of a divergent development of spreads of different maturities provoked sharp fluctuations in forward rates (e.g. the five-to-ten-year forward yield risk premium in Figure 4). It can be captured by introducing a factor that picks up the slope component of liquidity spreads in the model. Our liquidity stress factor features such a slope influencing component. It is the second PC derived from a set of differenced liquidity and volatility variables with different maturities of the underlying instruments. It shows reverse signs on the loadings of the eigenvectors of instruments of shorter maturities compared to longer maturities (see Table A.2 in the Appendix). An estimation of the model with the liquidity stress factor instead of the price factor and keeping the real activity factor shows a much smoother five-to-ten-year forward yield risk premium (see Figure 6) compared to the estimation without the liquidity factor. Yield risk premia of different maturities run much closer together once divergent liquidity premia are taken care of. There is nevertheless a shift in the forward risk premium at the end of 2008 at the start of the recent crisis. This shift can be

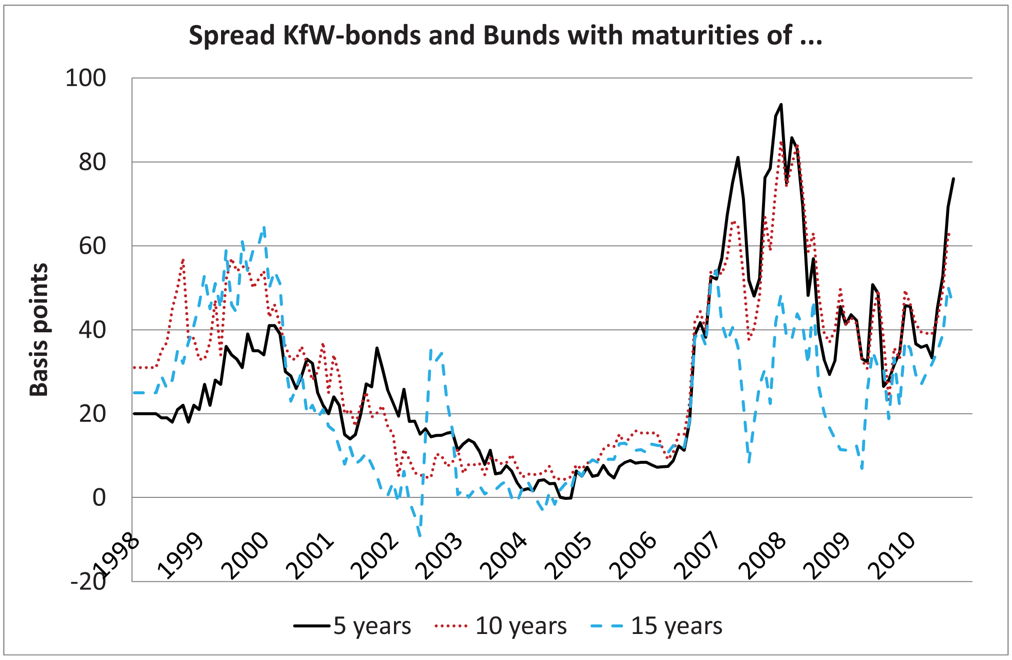


Figure 5: Spread between KfW bonds and Bunds for different maturities.

found in nearly all time series displaying liquidity, volatility or macro risks (see Figures 3 and 5). Liquidity risk variables like the KfW-Bund spread therefore explain a larger amount of the developments of forward premia than they do for forward interest rates.[11]

As a second approach to check for the influence of liquidity on bond yields, we estimate the macro model with a real activity and a price factor for the term structure of KfW bonds instead of Bunds. The model delivers a comparable fit ($RMSE^{mfKfW} = 0.03$) to the government bond model. The correlations of the yields with the macro factors are also alike (see Table A.3 in the Appendix). This means that fundamental influences on government bonds and KfW bonds are akin to each other. Yet, the correlation to the first latent factor is significantly negative (positive for Bunds) and the positive correlation to the second latent factor is much stronger for the KfW bond model. Since the first latent factor represents influences on levels of yields, this indicates that yields of both kind of bonds go in different directions. This is in agreement with the notion of safe haven flows going into the most liquid assets and therefore widening the spread between liquid (Bunds) and less liquid (KfW bonds) instruments. The much stronger effect of the second latent (slope) factor on KfW yields is a consequence of the shift in yield spreads of different maturities during times of crisis. The KfW macro model therefore mirrors findings where the liquidity factor in the government bond model is included but does not allow explicit conclusions on the government yield curve to be derived and is therefore not developed further.

Introducing a structural policy rule and macro factors into the affine term structure model helps to fundamentally ground long-term interest rate movements. The comparison of the yields-only model and the model with macro factors shows the yield influencing effect especially of the real activity factor. Impulse response functions corroborate that unanticipated changes in fundamental factors move the whole term structure for a significant period of time. The recent crises considerably affect risk aversion of market participants and yield risk premia derived within the

[11] The adjusted R^2 increases from 1% to 14% in univariate regressions with a dependent variable forward rate and forward premium, respectively.

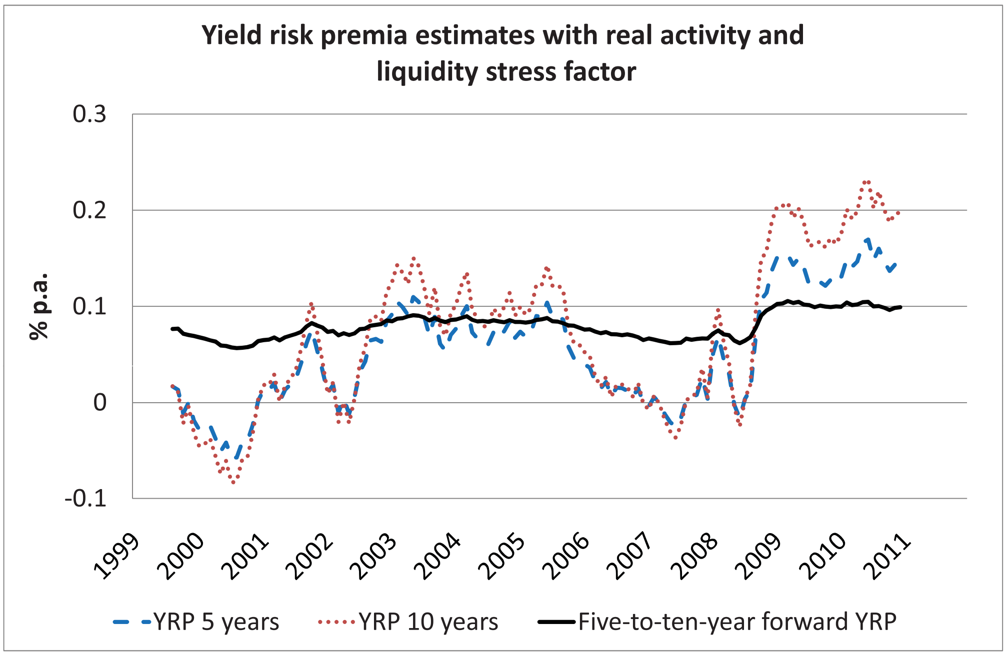


Figure 6: Yield risk premia for the model which includes a liquidity stress factor.

model. Since German government bonds are considered to be virtually credit risk free we included a liquidity factor to take care of the (liquidity) risk premium shifts. Including a slope influencing liquidity stress factor allows results to be derived from the real activity factor (and the latent factors) on the term structure without interference from safe haven flows.

5 Robustness checks

5.1 Estimates with different sample sizes

The ongoing financial crisis, which started as a subprime market exaggeration, turned into a banking crisis and subsequently a sovereign debt crisis, might suggest that not just single variable levels or time series developments changed but that more structural relations have also changed or are interrupted. In order to assess the instability of the influence of macro factors in the monetary policy rule and a subsequent shift in the coefficients of the affine equations for long-term rates, we split the sample into two parts. Since the crisis sample which starts in 2007 is too short to support a reliable estimation, we split the sample into a shorter pre-crisis period (1999-2006) and a whole period sample (1999-2010) - which are already quite short - and look at the difference in the reactions to latent and macro factors in both samples.

Estimations for the long sample and the short (pre-crises) sample period display comparatively good fits of the data, with the short sample showing slightly higher RMSEs for shorter maturities. State variables show comparable loadings over the course of the maturities as well with the exception of the price factor (see Figure A-2 in the Appendix). It shows a positive loading for all maturities within the long sample and a positive loading only for maturities of up to 7 months and a negative loading thereafter within the short sample. It may be the case that market participants do not adjust their expectations of future short-term rates by much during the period of the great moderation before the onset of the recent crises. Yet, the differences are statistically not significant and should therefore not be overemphasized. Overall loadings tend to be lower for longer maturities, implying that changes in contemporaneous macro variables have a greater influence on short-term compared to long-term interest rates. Our preliminary conclusion that the recent crises do not render the estimation of a long data sample starting in 1999 meaningless must of course be verified once estimations with crisis data only are viable.

5.2 Forecast experiments

Evaluating a model's out of sample forecasting performance is generally a good way to check its reliability. However, due to data availability, it is hardly possible for us to perform a reasonable forecasting exercise. We originally estimated the model for the sample from 1999 to 2010, hence about 140 periods. If we start out of sample forecasting from period 100 onwards till the end of the sample, we would have to deal with at least three problems. First, an initializing sample for the forecasting of only 100 periods is very short. Second, the 40 remaining periods for the forecasting sample are also not very much and should not be further reduced to expand the initializing sample. Third, and most importantly, such a forecasting period would fall in the period between October 2007 and December 2010 and thus directly in the crisis periods. Not surprisingly, the model is not able to deliver good forecasts for that period.
These problems cannot be cured by ignoring the structural break of the monetary union and starting the estimation before 1999. Especially our preferred model, the macro model with one lag, relies on some measures which did not exist before the European Monetary Union was established. However, we carried out a forecasting experiment with the latent factor approach for a longer sample (11/1982-09/2011). We expanded the Euribor/Eurepo rates by the money market rate reported by Frankfurt banks for the time before 1999. We chose a long forecasting sample, starting in February 1991 and running till August 2011 (hence also covering the crises). While the short maturity forecasts appear to be slightly disturbed by the use of different money market rates, the 10-years bonds could be forecasted one year ahead comparatively well with a root mean squared error of 0.81 percentage points.
The robustness checks are not conclusive in giving advice on the usage of the model with macro factors in the actual crisis period. Although the estimation results do not change significantly, the forecast performance breaks down. Indeed our model is just one viable approach to a fundamental interpretation of the German term structure. Yet it offers the advantage of including such fundamental macro factors besides unobservable factors that drive the term structure and assigns them a certain weight.

6 Conclusion

Using arbitrage-free affine models, we analyzed the dynamics of German bond yields and risk premia for the period 1999 to 2010. We condensed our macro factors from a vast set of time series describing the economic development in Germany, the euro area, the US, and the world as a whole. On the one hand, a heuristic shrinkage procedure helped us to preserve the sparse parameterization of our affine term structure set up by including just two macro factors. On the other hand, we were still able to catch the influence of a broad variety of real world developments in these two factors by maintaining a high proportion of variance explained of the underlying time series. We found evidence that our macro factors, notably the real activity factor, helped to improve the fit of the model and explained a substantial amount of variation in (future) bond yields. So even if short-lived variations in the term structure might be mainly driven by changes in the unobserved slope, level, and curvature factors, longer-term developments are more grounded within fundamental factors such as business cycle and growth trends. Looking at the impact of the recent subprime, financial and sovereign debt crises we see that particularly the market prices of risk for the real activity and the price factor changed most dramatically. Offsetting safe haven flows, which affect shorter maturities in particular, explain why yield risk premia increase less at the short end as compared to longer maturities in times of crisis. A liquidity stress factor included in the macro model mirrors this slope influencing effect and leads to smoother forward rates for yield risk premia. The slope influencing factor takes effect especially during times of crises and allows results to be derived from the real activity factor on the term structure without interference from safe haven flows.

Nonetheless, forecast experiments hint at more profoundly disturbing effects of the recent crises on the performance of the model. Future research might therefore be directed towards either enlarging the number of factors that describe market behavior during times of crisis or introducing modeling alternatives such as implementing macro factors as unspanned factors and therefore exploring their relation to yield risk premia more closely. Using the same model set up but different term structure data might be another rewarding extension to the paper. Since the macro data used comprises time series not only for Germany but euro-area, US, and world data, an estimation with US yields or yields of other European countries is viable.

A Appendix

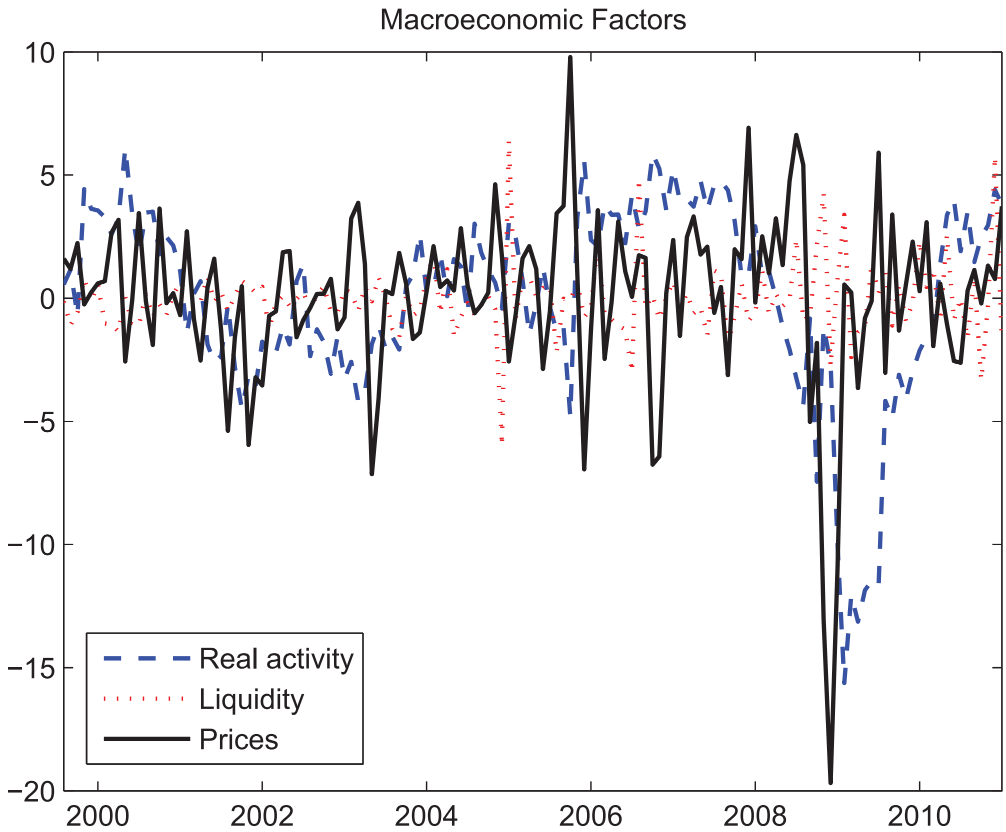


Figure A-1: The graph plots the factors for real activity, prices and liquidity that are used to incorporate macroeconomic information in the ATS estimation. Specifically, there are either the real activity and the price factor (Section 4.1) or the real activity and the liquidity factor (see Section 4.3) used as factors additionally to the latent factors.

Table A-1: Macro factors: explained variance of principal components, significance in univariate regressions and correlation with each other.

Macro factor	Eigenvalues: Proportion of 1st PC	Correlation to first macro factor	Regress. on short rate: Coefficient (T stat)* [Adj. R^2]	Regress. on 1st latent fac.: Coefficient (T stat)* [Adj. R^2]
Real activity factor	0.38	-	0.026 (4.35) [0.35]	0.052 (2.22) [0.05]
Price factor	0.74	0.35	0.017 (1.64) [0.10]	0.031 (1.26) [0.02]
Liquidity stress factor	0.33	-0.08	-0.03 (2.30) [0.05]	-0.09 (1.93) [0.03]

** Standard errors with Bartlett kernel, Newey-West fixed and heteroscedasticity and autocorrelation consistent.*

Table A-2: The liquidity stress factor is extracted through principal component analysis for the sample August 1999 to December 2010. The table provides eigenvectors (loadings) of the principal components for a subset of included liquidity measures. The second principal component shows reverse signs on the loadings of the eigenvectors of instruments of shorter maturities compared to longer maturities.

Variable	$1^{st} PC$	$2^{nd} PC$
KfW-Bund-Spread, 1 year to maturity	0.28	-0.08
KfW-Bund-Spread, 2 years to maturity	0.27	0.05
KfW-Bund-Spread, 3 years to maturity	0.32	0.05
KfW-Bund-Spread, 4 years to maturity	0.32	0.02
KfW-Bund-Spread, 5 years to maturity	0.35	-0.02
KfW-Bund-Spread, 7 years to maturity	0.33	-0.13
KfW-Bund-Spread, 8 years to maturity	0.31	-0.15
KfW-Bund-Spread, 9 years to maturity	0.33	-0.08
KfW-Bund-Spread, 10 years to maturity	0.31	-0.07
KfW-Bund-Spread, 15 years to maturity	0.22	-0.02

Table A-3: Correlation of the yields that are assumed to be measured with error to the model factors for estimation with KfW bonds (sample: July 1999 to December 2010).

	$y(12m)$	$y(60m)$	$y(120m)$
Contemporaneously:			
Real activity factor	0.34	0.26	0.11
Price factor	0.08	0.09	0.06
1st Latent	-0.21	-0.28	-0.47
2nd Latent	0.97	0.90	0.79
3rd Latent	0.20	-0.18	-0.45
12m-lagged:			
Real activity factor	0.70	0.56	0.39
Price factor	0.09	0.04	-0.00
1st Latent	0.14	-0.10	-0.32
2nd Latent	0.43	0.57	0.70
3rd Latent	0.11	0.05	-0.05

Table A. 4: Data description

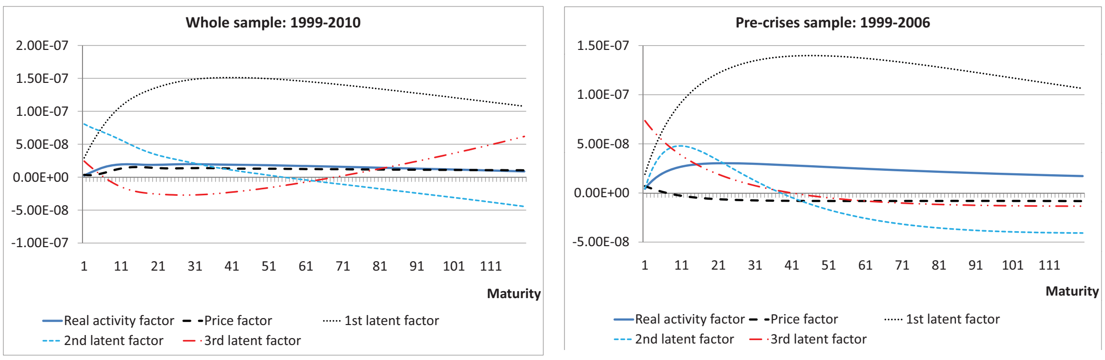
	Variable	Transformation*	Source
EMU time series			
Prices	Wholesale producer prices, All items, sa	5	BIS
Surveys	Business confidence indicator, sa	1	BIS
	EMU Construction - Business situation: present , sa / Quantum (non-additive or stock figures) , sa	1	OECD
	EMU Construction - Employment: future tendency , sa / Quantum (non-additive or stock figures) , sa	1	OECD
	EMU Manufacturing - Industrial confidence indicator , sa / Quantum (non-additive or stock figures) , sa	1	OECD
	EMU Manufacturing - Employment: future tendency , sa / Quantum (non-additive or stock figures) , sa	1	OECD
	EMU Services - Business situation: present , sa / Quantum (non-additive or stock figures) , sa	1	OECD
Industry production	EMU Production of total industry / Index publication base , sa	2	OECD
Volatility	Implied volatility of 3-month Euribor, annualized	2	Bloomberg
	Overnight indexed swaps Euribor spread	2	Bloomberg
	Historical volatility of 3-month Euribor, annualized	2	Bloomberg
	Spread 3-month Euribor and 3-month German treasury bills	2	Bloomberg
	Usage of Marginal Lending Facility in euro area	2	ECB
	Yield spread of AAA non financial corporations to government bonds for 7 to 10-year maturities	5	Bloomberg
	Historical Volatility of 10-year interest rate swap, annualized	5	Bloomberg
German time series			
Domestic prices	Producer price index without energy, sa	5	Bundesbank dataset
	Import prices, Energy, sa	5	Bundesbank dataset
Labor market	Employees and self employed, manufacturing, sa	5	Bundesbank dataset
	Domestic labor force, sa cda	5	Bundesbank dataset
	Labor force volume, sa cda	5	Bundesbank dataset
	Labor productivity per man-hour worked: Domestic labor force, sa cda	5	Bundesbank dataset
	Labor productivity per man-hour worked: Labor force, sa cda	5	Bundesbank dataset
	Gross wages and salaries: domestic labor force, sa cda	5	Bundesbank dataset
	Unit labor cost: Domestic labor force, sa cda	5	Bundesbank dataset
	Unit labor cos on a hourly basist: Domestic labor force, sa cda	5	Bundesbank dataset
Surveys	IFO surveys: Business climate: Capital good producers	1	Bundesbank dataset
	IFO surveys: Business expectations for the next six months: Capital good producers	1	Bundesbank dataset
	IFO surveys: Business expectations for the next six months: Durable consumer good producers	1	Bundesbank dataset
	IFO surveys: Business expectations for the next six months: Retail trade	1	Bundesbank dataset
	IFO surveys: Business expectations for the next six months: Wholesale trade	1	Bundesbank dataset
	IFO surveys:Stocks of finished goods: Capital good producers	1	Bundesbank dataset
	Consumer confidence	1	Bundesbank dataset
	GFK consumer surveys: Business cycle expectations	1	Bundesbank dataset
Capacity utilization	Ifo business cycle index: Capacity utilization: Manufacturing	1	Bundesbank dataset
	Ifo business cycle index: Capacity utilization: Intermediate goods	1	Bundesbank dataset
	Ifo business cycle index: Capacity utilization: Consumer goods	1	Bundesbank dataset
	GDP, sa cda	5	Bundesbank dataset
Liquidity	Spread of KfW bonds and German Federal securities with maturity of 1 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 2 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 3 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 4 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 5 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 7 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 8 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 9 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 10 Year	2	Bloomberg
	Spread of KfW bonds and German Federal securities with maturity of 15 Year	2	Bloomberg
	Bid-ask spread for German Federal securities with maturity of 2 years	2	Bloomberg
	Bid-ask spread for German Federal securities with maturity of 10 years	2	Bloomberg
	Implied volatility of 10-year Bunds, annualized	2	Bloomberg
	Historical volatility of 10-year Bunds, annualized	2	Bloomberg

Table A. 4: Data description contind.

	Variable	Transformation*	Source
US time series			
Prices	CPI: all items (urban)	5	Bureau of Labor Statistics
	CPI: transportation	5	Bureau of Labor Statistics
	CPI: commodities	5	Bureau of Labor Statistics
	CPI: all items less food	5	Bureau of Labor Statistics
	CPI: all items less shelter	5	Bureau of Labor Statistics
	CPI: all items less medical care	5	Bureau of Labor Statistics
	PCE: chain weight price index: Total	5	Bureau of Economic Analysis
	PCE prices: nondurables	5	Bureau of Economic Analysis
	PCE prices: services	5	Bureau of Economic Analysis
	PPI: finished goods (1982=100 for all PPI data)	5	Bureau of Labor Statistics
	PPI: finished goods less food and energy	5	Bureau of Labor Statistics
	PPI: finished consumer goods	5	Bureau of Labor Statistics
	PPI: intermediate materials	5	Bureau of Labor Statistics
	PPI: crude materials	5	Bureau of Labor Statistics
Industrial productio	Final Products and non-industrial supplies	2	Board of Governors of the Federal Reserve System
	Materials, nonenergy, durables	2	Board of Governors of the Federal Reserve System
	Mfg. (NAICS)	2	Board of Governors of the Federal Reserve System
	Non-energy, total (NAICS)	2	Board of Governors of the Federal Reserve System
	Non-energy excl CCS (NAICS)	2	Board of Governors of the Federal Reserve System
	Non-energy excl CCS and MVP (NAICS)	2	Board of Governors of the Federal Reserve System
Capacity utilization	Capacity Utilization: Total (NAICS)	2	Board of Governors of the Federal Reserve System
	Capacity Utilization: Mfg. (NAICS)	2	Board of Governors of the Federal Reserve System
	Capacity Utilization: Mfg. excl CCS	2	Board of Governors of the Federal Reserve System
Employment	Employment on nonag payrolls: Manufacturing, nondurables	5	Bureau of Labor Statistics
	Employment on nonag payrolls: Transportation and warehousing	5	Bureau of Labor Statistics
Surveys	ISM mfg index: inventories	1	Bureau of Economic Analysis
	ISM mfg index: new orders	1	Institute for Supply Management
	Chicago Fed Midwest Mfg. Survey: General activity	1	Federal Reserve Bank of Chicago
	Outlook: Inventories	2	Federal Reserve Bank of Philadelphia
	Outlook: Unfilled orders	2	Federal Reserve Bank of Philadelphia
	Outlook: Employment	2	Federal Reserve Bank of Philadelphia
	Outlook: Work hours	2	Federal Reserve Bank of Philadelphia

*) Transformation according to Stock and Watson (2008); 1=unchanged, 2=1st diff., 3=2nd diff., 4=ln, 5=ln 1st diff., 6=ln 2nd diff. Sa = seasonally adjusted, cda = calendar day adjusted, nsa = non seasonally adjusted.

Figure A-2: Loading of state variables on yields of different maturities with different sample sizes.



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