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Forecasting the US term structure of interest rates using a macroeconomic smooth dynamic factor model

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ABSTRACT

We extend the class of dynamic factor yield curve models in order to include macroeconomic factors. Our work benefits from recent developments in the dynamic factor literature related to the extraction of the common factors from a large panel of macroeconomic series and the estimation of the parameters in the model. We include these factors in a dynamic factor model for the yield curve, in which we model the salient structure of the yield curve by imposing smoothness restrictions on the yield factor loadings via cubic spline functions. We carry out a likelihood-based analysis in which we jointly consider a factor model for the yield curve, a factor model for the macroeconomic series, and their dynamic interactions with the latent dynamic factors. We illustrate the methodology by forecasting the U.S. term structure of interest rates. For this empirical study, we use a monthly time series panel of unsmoothed Fama–Bliss zero yields for treasuries of different maturities between 1970 and 2009, which we combine with a macro panel of 110 series over the same sample period. We show that the relationship between the macroeconomic factors and the yield curve data has an intuitive interpretation, and that there is interdependence between the yield and macroeconomic factors. Finally, we perform an extensive out-of-sample forecasting study. Our main conclusion is that macroeconomic variables can lead to more accurate yield curve forecasts.

1. Introduction

The forecasting of interest rates for different maturities, known as the yield curve or the term structure of interest rates, has attracted a considerable amount of interest. Initially, forecasting was based only on yield curve information. Recently, the literature has focussed on the strong relationship between the yield curve and macroeconomic variables; see, for example, Ang and Piazzesi (2003) and Diebold, Rudebusch, and Aruoba (2006). This has led to a renewed interest in the use of macroeconomic information in forecasting the yield curve; see for example Exterkate, Van Dijk, Heij, and Groenen (2010) and Moench (2008). We construct a dynamic factor model for a joint likelihood-based analysis of the term structure of interest rates and a large panel of macroeconomic series. In particular, the main focus of our study is on estimating the parameters by the maximum likelihood method, extracting the factors from the joint dynamic factor model and forecasting the term structure of interest rates.

Our analysis builds on contributions from the literature on the general dynamic factor model, which is increasingly playing a major role in econometrics. These contributions have emerged from work in the 1970s, including the work of Bai (2003), Connor and Korajczyk (1993), Forni, Hallin,

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Lippi, and Reichlin (2000), Geweke and Singleton (1981), Gregory, Head, and Raynauld (1997), Sargent and Sims (1977), Stock and Watson (2002) and Watson and Engle (1983). We consider the use of exact maximum likelihood methods, which were explored by Doz, Giannone, and Reichlin (2012), Jungbacker and Koopman (2008) and Watson and Engle (1983). Examples of articles which employ likelihood-based methods for the analysis of dynamic factor models include those of Engle and Watson (1981), Jungbacker, Koopman, and van der Wel (in press), Quah and Sargent (1993) and Reis and Watson (2010).

Here, we build on the econometric likelihood-based framework for dynamic factor models with smooth factor loadings, as was considered by Jungbacker et al. (in press). The smoothness conditions on the loadings are introduced via spline functions that depend on knot coefficients; see Poirier (1976). The parameters in the model are estimated via a maximum likelihood procedure that allows smoothness to be imposed on the factor structure. There are several motivations for imposing smoothness on the factor loadings in a dynamic factor model. The economic motivation is to establish an interpretation for the factors. When the factor loadings are related to particular characteristics of the corresponding variables in the panel, we can impose this relationship by specifying a smooth flexible function for the factor loading coefficients. A smooth pattern in a column of the loading matrix can lead to an interpretable factor that is associated with this column. In our empirical study for a panel of interest rates, we impose smoothness on the loadings through a spline function that depends on the time to maturity. The common interpretation of the factors as the level, slope and curvature of the yield curve can be established. Also, for the macroeconomic variables, we can consider a smooth relationship between the underlying factors and observations. The econometric motivation for smooth loadings is partly the desire for a parsimonious model specification where individual loading coefficients are interpolated by a flexible function that depends on a small number of coefficients. The precision of the parameter estimates is generally increased by considering models which are more parsimonious. Furthermore, smoothness in the factor loadings may also lead to models that are more robust to aberrant observations. It is also often argued that forecasts which are based on a model with a small set of parameters can be expected to be more precise than those based on a less parsimonious model; see the discussion by Clements and Hendry (1998).

We extract a small number of latent factors from a large panel of macroeconomic series using the general dynamic factor model. We do this following Stock and Watson (2002), who extract latent factors from a similarly large panel of economic time series in order to forecast eight macroeconomic series. However, unlike Stock and Watson (2002), we adopt the Jungbacker and Koopman (2008) likelihood-based framework for extracting the common factors jointly from the yield data and from the panel of macroeconomic variables. The dynamic specifications of the macro and yield factors are also specified jointly in the smooth dynamic factor model. In this way, we obtain a macroeconomic smooth dynamic factor model that can analyse the yields and the panel of macroeconomic series simultaneously. Parameter estimation, the extraction of factors and forecasting all take place in a unified likelihood-based analysis. Although the computational requirements can be severe for large dimensional models, the extent of our empirical study implies that the likelihood-based approach is feasible.

The interactions between the term structure of interest rates and macroeconomics are reviewed thoroughly by Gürkaynak and Wright (2012). In light of their study, it may be of interest to investigate empirically whether the inclusion of macroeconomic factors in the smooth dynamic factor model is effective, by means of a forecasting study for a panel of US interest rate series for different times to maturity. Cochrane and Piazzesi (2005) and Ludvigson and Ng (2009) empirically explored the effects of including macroeconomic fundamental variables and business cycle dynamics for the forecasting of excess bond returns, and found evidence that macroeconomic variables can provide important information for forecasting the yield curve. It is often found that imposing no-arbitrage conditions does not lead to more accurate forecasts. Hence, we are not considering the incorporation of no-arbitrage conditions for affine term structure models, as did Duffie and Kan (1996), for example. Formal arguments for the invariance of no-arbitrage conditions in a dynamic term structure model for yield forecasting are given by Joslin, Singleton, and Zhu (2011), and related discussions are provided by Duffee (2011).

The primary aim of our empirical study is to investigate whether adding a panel of macroeconomic time series variables to the smooth dynamic factor model will lead to more accurate forecasts of the yield curves. The forecasting results are presented for a set of different model specifications, both with and without the macroeconomic variables. We also consider two alternative model-based forecasting procedures for the yield curve, specifically the methods based on the dynamic Nelson–Siegel and functional signal plus noise models. The former relies on the seminal article by Nelson and Siegel (1987) and the two-step procedure for the forecasting of yield curves, as proposed by Diebold and Li (2006). Generalizations of this approach to yield forecasting are developed by Diebold et al. (2006) and Koopman, Mallee, and Van der Wel (2010). The second forecasting method was discussed recently by Bowsher and Meeks (2008); they specify the yield curve as a cubic spline function with time-varying parameters that is observed with noise. For all of the forecasting methods, we represent the underlying models in state space form and carry out the necessary computations by means of the Kalman filter and related methods; see, among others, Durbin and Koopman (2012). All computations are carried out using the routines provided by Koopman, Shephard, and Doornik (1999, 2008).

The empirical study considers a monthly time series panel of unsmoothed Fama–Bliss zero yields for US treasuries of different maturities between 1970 and 2009. From the smooth dynamic factor model, we obtain the usual level, slope and curvature factors. The panel of 110 macroeconomic series provides factor estimates corresponding to the real economy, price indices, and labor and

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